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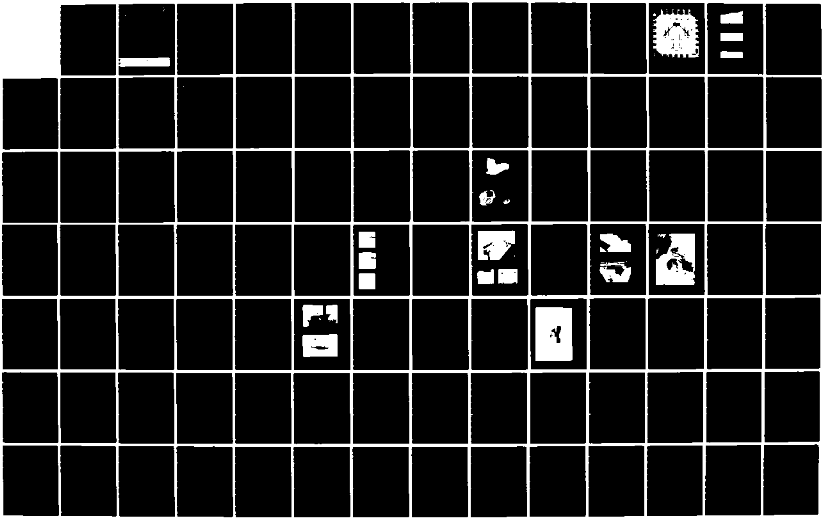

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AD-A145 214

TECHNICAL REPORT NAVTRAEQUIPCEN IH-353

ANALYSIS OF ON-BOARD COMPUTER IMAGE GENERATOR (CIG) APPLICATIONS FOR AIRCREW TRAINING

Advanced Simulation Concepts Laboratory
Naval Training Equipment Center
Orlando, Flordia 32813

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This report presents the results of a study examining the potential use of on-baord Computer Image Generation (CIG) for Naval aircrew training.

Three criteria determine whether on-board CIG may be applied to a particular training task. The aisplays available in the cockpit must be suitable, generation of adequate imagery must be feasible, and the training problem must be appropriate. To determine each of these factors, surveys in each area were conducted. An analysis of the survey results is presented.

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The development and use of on-board CIG based training systems was concluded to be feasible and would enhance operational readiness. The report includes specific recommendations as regards training tasks that would benefit most from application of on-board CIG and would also be technically feasible. Three approaches to such application are:

- Utilization of existing and planned on-board hardware in training modes,
- Development of a training computer image generator as a pod to be mounted temporarily on a weapon station for training missions,
- Lond term merging of training and tactical considerations in the development plase of new weapon systems and avionics.

All three approaches should be pursued in parallel.

NAVTRAEQUIPCEN IH-353

Contact No. N60921-82-D-A075

DCS Report No. LT0010

ANALYSIS OF ON-BOARD COMPUTER IMAGE GENERATOR (CIG) APPLICATIONS FOR AIRCREW TRAINING

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April 84

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SECTION I

Introduction/Background

The training of Navy personnel is critical to the success of Naval operations. As equipment becomes more complex and task loading increases, training becomes both more difficult and more essential. This is illustrated in the training of aircrews where a stepped approach to training is standard. After completing the initial stages of training, a new pilot is sent to an operational squadron where training continues at a different level and is increasingly oriented toward the combat arena.

The combat arena, however, is difficult to reproduce short of actual combat. Test ranges for combat practice and ground-based combat mission simulators can go a long way toward reproducing the combat environment. A crew's opportunities to practice in these environments are limited by the expense and logistics involved. Another training limitation stems from the deployment of operational aircrews. In order to maintain readiness, weapon system platforms, including aircraft, ships, and submarines, are deployed in areas where it is inconvenient or inefficient for platform crews to utilize simulation systems at training sites to maintain and enhance skill proficiency.

What is needed is a method to make the normal, everyday operating environment of the military weapon system crew more like the real combat environment he will face in case of hostilities. A significant step toward this goal can be taken by utilizing the advanced display capabilities of modern weapon systems. The old gauges and dials are being replaced with cathode ray tubes and other flexible display technologies (see Figure 1). Simulated images, presented on these displays in flight or on board ship, can provide the crew with more opportunities to practice their missions productively.

Computer Image Generation (CIG) technology potentially can provide these images. (See Figure 2). Generation of images by computer has become the standard approach for ground-based visual simulation. The state of the art in this technology now allows consideration of designing and packaging much smaller CIG systems than previously possible. Thus, the time has come to consider the feasibility and utility of putting such systems on deployed weapons platforms such as ships, submarines, and aircraft. The

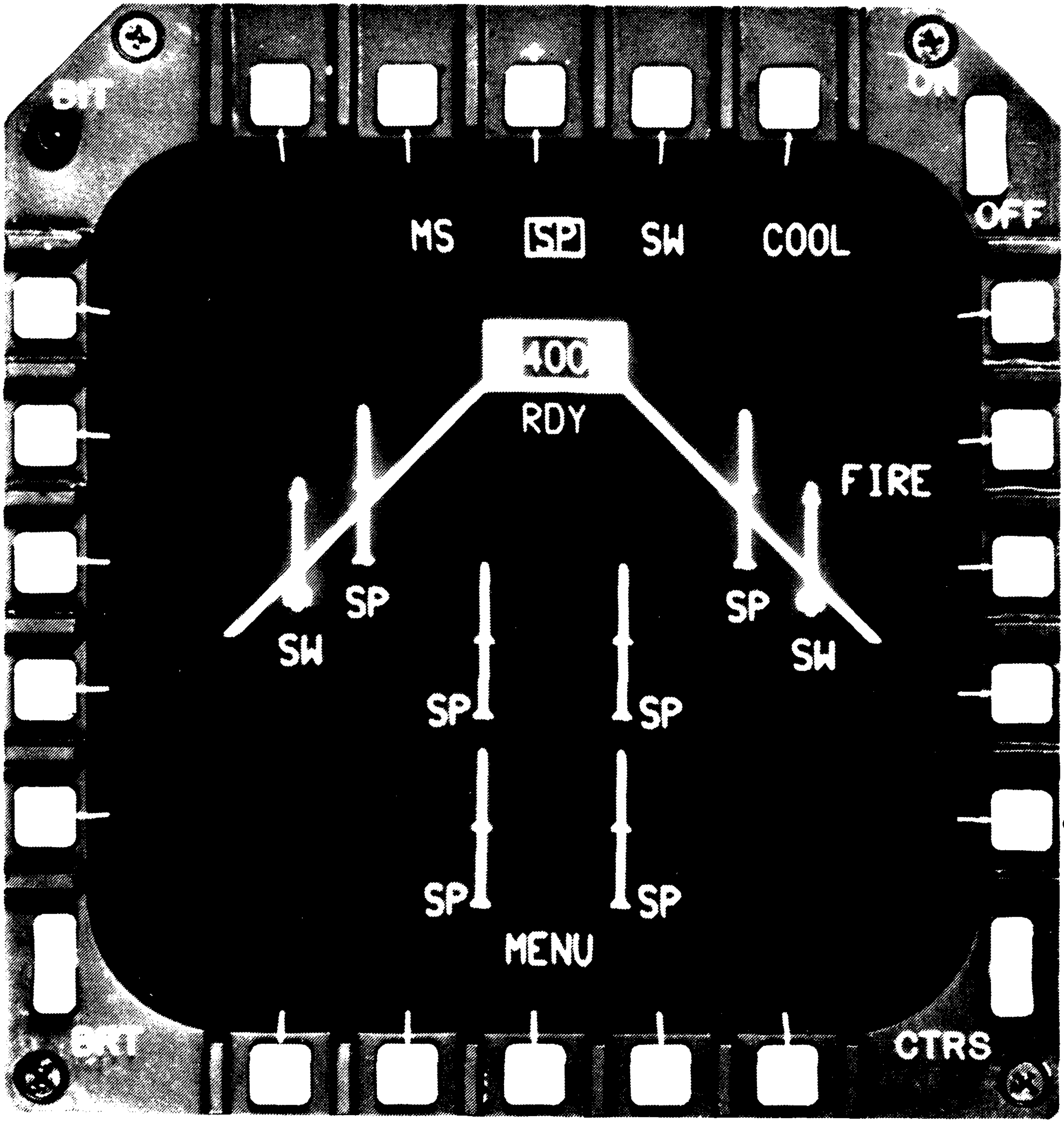


Figure 1. Example Multifunction Display

(Courtesy of Sperry Flight Systems). Note: the buttons around the display perimeter have software controlled functions corresponding to the labels around the display perimeter. When the display mode is changed, the labels and functions of the buttons change.

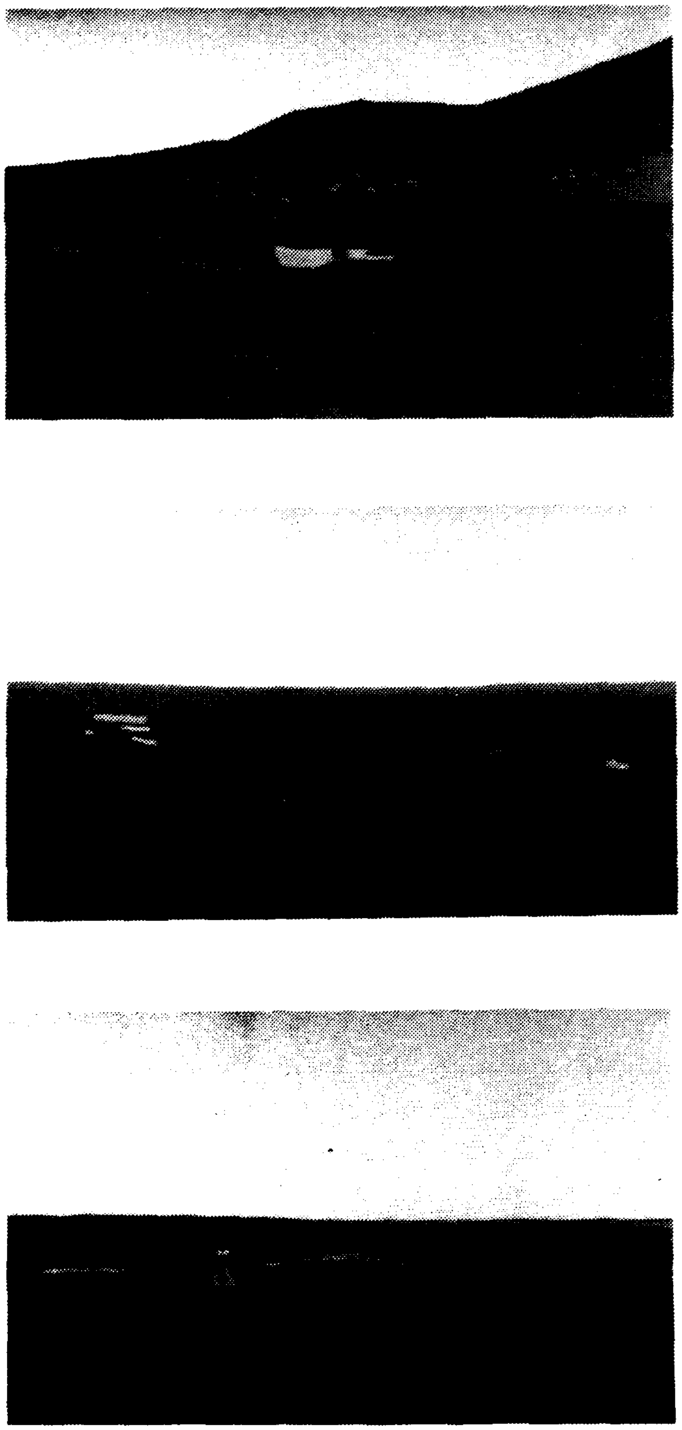


Figure 2. Sample of Ground Based Computer Generated Images of Terrain (courtesy of Boeing Company, Inc.).

application of concern in this study is training although operational applications are also possible.

Aircrew training was chosen by the Government as the initial application for development of on-board CIG training techniques and equipment. Examples of possible training scenarios include: sensor display simulation of combat scenarios while at sea; and simulation of adversary aircraft or ground-based threats while flying at sea or over friendly territory. The development of an on-board CIG system would also allow the presentation of graphic displays containing artificial cues to enhance training. Examples of these are energy-maneuverability diagrams (see Figures 3 and 4) and "bullets at target range" (Figure 5). Applications can also include rehearsal for specific combat missions.

Summary

This report presents the results of a study examining the potential use of on-board Computer Image Generation (CIG) for Naval aircrew training.

Several criteria determine whether onboard CIG may be applied to a particular training task. The displays available must be suitable, generation of adequate imagery must be feasible, and the training problem must be appropriate. To determine each of these factors, surveys in each area were conducted.

The study included three survey efforts. The first was a survey of existing, planned, and predicted Navy cockpit displays. The second was a survey of the state-of-the-art in computer image generation. The third was a survey of Naval aviation training tasks and techniques that might be addressed with on-board computer image generation.

In addition to the detailed results of the study, the report includes specific recommendations as regards training tasks that would benefit most from on-board CIG where this enhancement is technically feasible. Discussions of the surveys of cockpit displays and computer image generation are followed by a discussion of how the results relate to specific training tasks. This, in turn, is followed by an over-all analysis, and by conclusions and recommendations. Table 1 (Volume II) summarizes the survey results and conclusions.

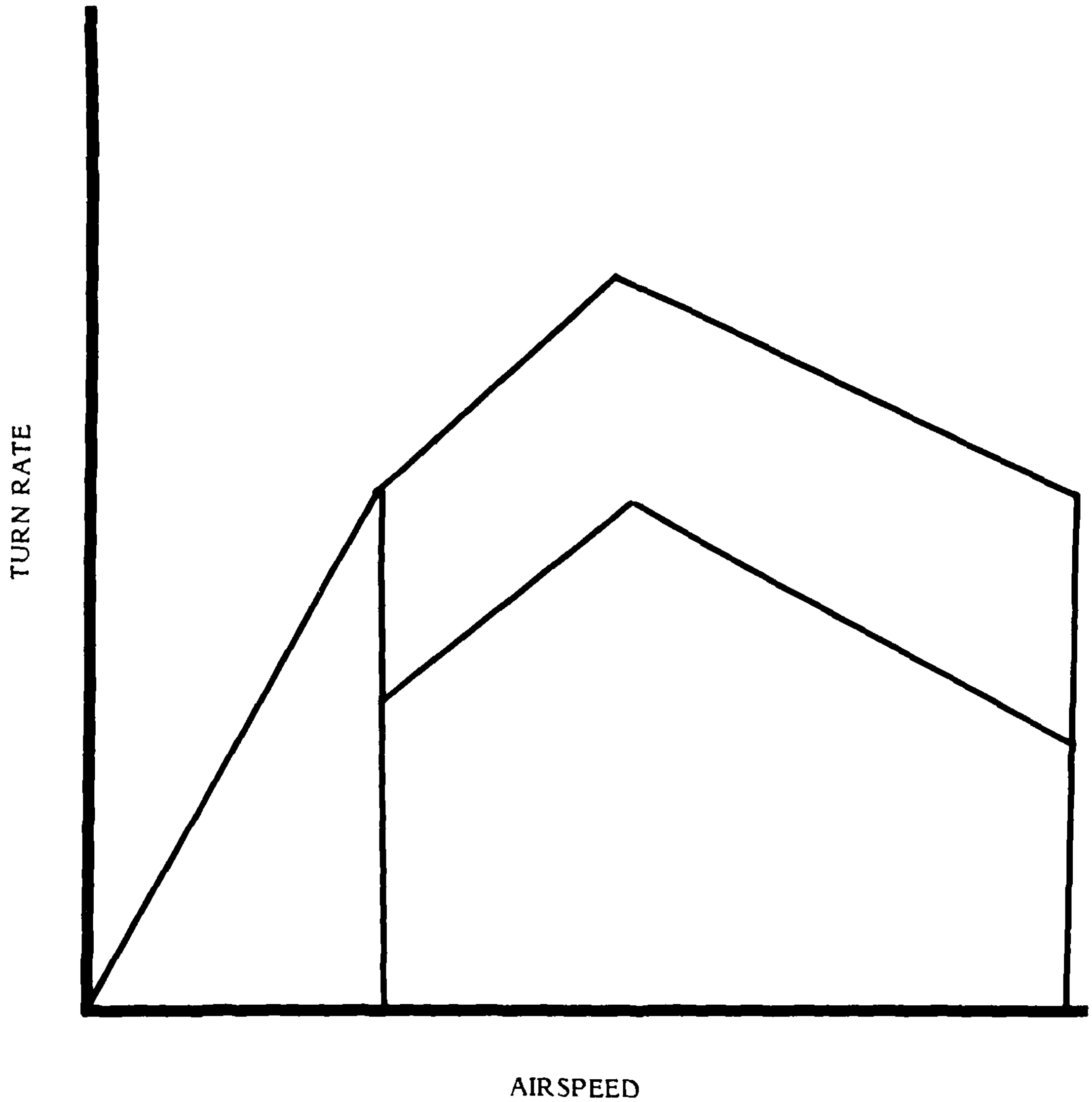


Figure 3. Basic Energy Maneuverability Diagram Used to Train Maximum Performance Flight for Air Combat.

1) SPEED = 0 TURN RATE = 0

2) SPEED = MINIMUM AT FULL THROTTLE AND AFTERBURNER
TURN RATE = 0

3) SPEED = MINIMUM AT FULL THROTTLE AND AFTERBURNER
TURN RATE = MAXIMUM SUSTAINABLE AT THIS SPEED

4) SPEED = MINIMUM AT FULL THROTTLE AND AFTERBURNER
TURN RATE = MAXIMUM AT THIS SPEED

5) SPEED = SPEED OF MAXIMUM SUSTAINABLE TURN RATE
TURN RATE = MAXIMUM SUSTAINABLE

6) SPEED = SPEED OF MAXIMUM TURN RATE
TURN RATE = MAXIMUM

7) SPEED = MAXIMUM TURN RATE = MAXIMUM AT THIS SPEED

8) SPEED = MAXIMUM TURN RATE = MAXIMUM SUSTAINABLE AT THIS SPEED

9) SPEED = MAXIMUM TURN RATE = 0

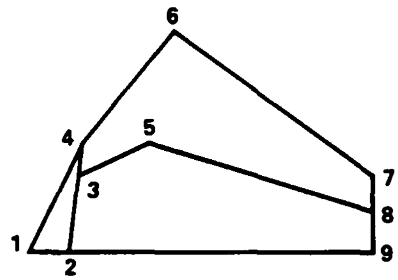
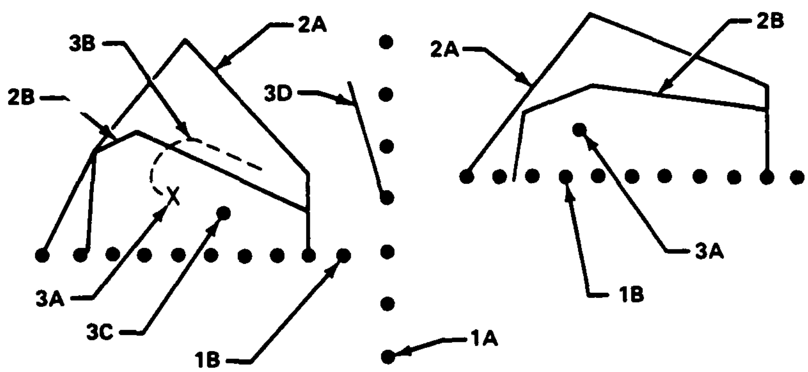


Figure 4a. Key Points in an Energy Maneuverability Diagram.



1. THE AXES SYSTEMS WHICH CONSIST OF (A) THE ALTITUDE AXIS AND (B) THE VELOCITY AXIS FOR EACH AIRCRAFT;
2. THE FLIGHT ENVELOPES OF THE HOST SIMULATOR AND AN ENEMY AIRCRAFT SHOWING (A) THE MAXIMUM TURN RATE AT EACH VELOCITY AND (B) THE SUSTAINABLE TURN RATE AT FULL THROTTLE FOR EACH VELOCITY; AND
3. THE AIRCRAFT ENERGY STATE INDICATORS WHICH INCLUDE (A) THE AIRCRAFT'S CURRENT STATE, (B) THE HOST MARKER TRAIL, (C) THE ENEMY AIRCRAFT'S EQUIVALENT SPEED MARKER, AND (D) THE RELATIVE ENERGY GAIN INDICATOR.

Figure 4b. An Alternate Form of Energy Maneuverability Diagram Applicable to One Versus One Combat.

AIM-GUNS

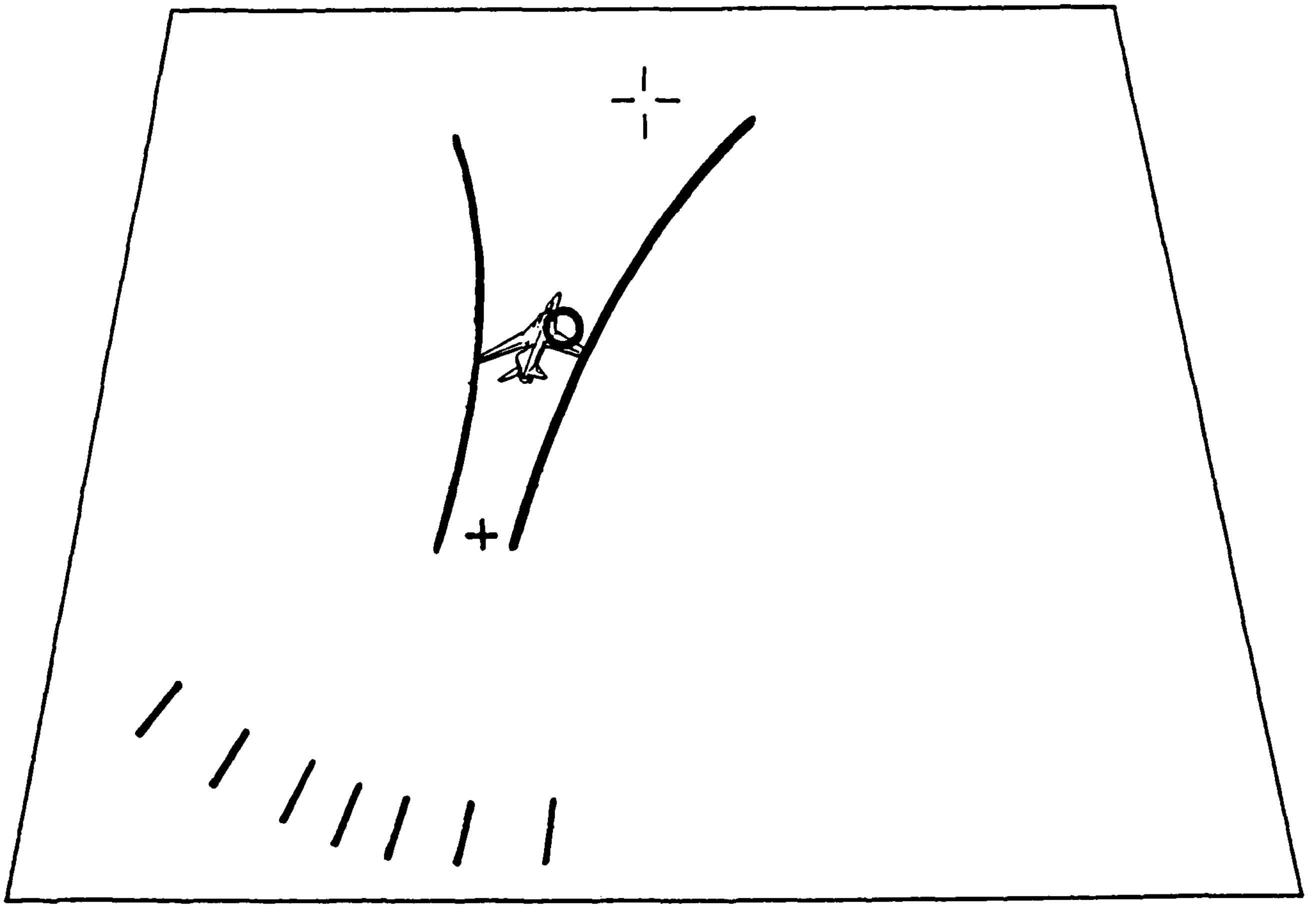


Figure 5. AIMGUNS Display

(Courtesy of General Electric Co.) as it would appear on a Head-Up Display (HUD) showing "bullets at target range" (circle) and range guides (curved lines).

TRAINING APPLICATIONS RELATED TO CIG AND DISPLAY CAPABILITIES

Table 1.

DCS CORPORATION

	CIG Requirements	Display Requirements	Existing CIG Usable	Existing Display Usable	Existing Application	Planned CIG Usable	Planned Display Usable	Additional Planned A/C Application
Key to Symbology	S'=Symbology G=Graphics (2or3D) R=Realistic (*)	Type (*)	Y=Yes N=No M=Maybe (Type)or(*)	Y=Yes N=No M=Maybe	Aircraft Type	Y=Yes N=No M=Maybe	Y=Yes N=No M=Maybe N/C = No Change	N/C = No Change
Air to Air Environment								
Fixed Wing								
Combat Maneuvering	S'(R),(G(D)	HMD(D)HUD(R)	Y (Firefly) (Aimgun)	M(Partial HUD)		Y	Y	F-14D
Air Refueling	G(R),R(D)	HMD(D)	N	N		N	N	
Formation Flying	G-2D(R),R(D)	HMD(D)	N	N		N	N	
Airborne Threat Avoidance	S'(R),G(D)	HMD(D),HUD(D) HSI(R),RWR(R)	M(Gaertner)	Y(Partial	F-4	Y	Y HUD HSI	A-6,F-18, F-14,F-4
Air Intercept	S'(R),G(D)	HUD(R),PAN(R)	Y(Firefly)	HUD)	E-2C		N/C	
Rotary Wing								
Formation Flight	G(D),R(D)	HMD	Y(G) N(S)	Y HUD		Y	N/C	CHMH53
Airborne Threat Avoidance	N/A(S)	HMD HUD HSI RWR	N/A(S)	Y HUD HMD		N/A	N/C	N/C
Air to Surface Environment								
Fixed Wing								
Visual Navigation	G-3D(R),R(D)	HMD(R)	M(G)	Y HSI.VDI HUD or HMD	F-18		N/C	N/C
Visual Reconnaissance	R(R)	HMD(R)	N	Y FLIR	F-18		N/C	N/C
Target Acquisition	R(R)	HUD(D),PAN(R)[c]	N(G)	Y HUD,TID Y TID MFD	E-2C		N/C	N/C
Weapons Delivery					F-18			
Bombs	G-3D(R)	HUD(D),PAN(R)	Y	Y TID MFD	F-14	Y	N/C	N/C
Visually Guided Missiles	G-3D(R)	PAN(R),HUD(D)	Y	Y TID MFD	H-60	Y	N/C	N/C
Gunnery	G-3D(R)	HUD(R)	Y	Y TID MFD	P-3C	Y	N/C	N/C
Takeoff/Landing (Field)								
Day	G-3D(R),R(D)	HUD(R) ACLS	Y	Y HUD HMD	F-18	Y	N/C	N/C
Night	G-3D(R),R(D)	HUD(R),HMD(D)	Y	Y HUD HMD	F-18	Y	N/C	N/C
Takeoff/Landing (Carrier)								
Day	G-3D(R),R(D)	HUD(R)	Y	Y HUD	F-18	Y	N/C	N/C
Night	G-3D(R),R(D)	HUD(D),PAN(R)	Y	Y HUD	F-18	Y	N/C	N/C
Low Level Flight	G-2D(R),R(D)	HUD(D),PAN(R)	$			Y	N/C	N/C
Low Level Navigation	G-2D(R),R(D)	HUD(D),PAN(R)	$			Y	N/C	N/C
Rotary Wing								
Visual Navigation	R(R)	HMD(R)	N	Y MFD	SH-3H		N/C	N/C
Visual Reconnaissance	R(R)	HMD(D),PAN(R)	N				N/C	N/C
Target Acquisition	R(D),G-3D(R)	HMD(D),PAN(R)	N				N/C	N/C
Weapons Delivery								
Bombs	R(D) S'(R)						N/C	N/C
Visually Guided Missiles	G-3D(R)	HUD(D),PAN(R)	Y			Y	N/C	N/C
Gunnery	N/A	N/A	N/A			N/A	N/C	N/C
Anti Sub Warfare	G3-D(R),R(D)	PAN(R)	N	Y TDD M MFD	S-3 SH-3H	Y	N/C	N/C
Confined Area Manuevering	G-3D(R),R(D)	HMD(D),PAN(R) HMD(STEREO)(D)	N				N/C	N/C
Low Level Piloting	R(R)	PAN(R),HUD(D)	N				N/C	N/C
Low Level Navigation								
Takeoff/Landing (Field)								
Day	G-3D(R),R(D)	HMD(R)	Y		SH-3	Y	N/C	N/C
Night	G-3D(R),R(D)	HMD(R)	Y			Y	N/C	N/C
Takeoff/Landing (Carrier)								
Da/	G-3D(R),R(D)	No Adequate Display	Y			Y	N/C	N/C
Night	G-3D(R),R(D)		Y			Y	N/C	N/C
Mine Sweeping	R(R)#		N		SH-3H		N/C	N/C
Sensory Environment								
Radar/Radar Landmass	R(R)	PAN(R)	N	MFD	A7,SH3H,F14		N/C	N/C
TV-Data Link	G-3D(R),R(D)	PAN(R)	Y	Walleye FLIR	E2C,SH2F A6,EA6B,F18 A4M,P3,S3	Y	N/C	N/C
Forward Looking Infrared	G-3D(R),R(D)	PAN(R),HUD(D) HMD(D)			S3,P3,F18	N	N/C	N/C
Sonar or Acoustic Sensor	G-2D(R)&Sound	PAN(R)	Y	CRT (Sonar)	S3,SH3H,EA6B	Y	N/C	N/C
Electronic Counter Measures	S'(R) G(R)	RWR(R)	Y		E2C	Y	N/C	N/C

TRAINING APPLICATIONS RELATED TO CIG AND DISPLAY CAPABILITIES (Cont.)

Predicted CIG	Predicted Display Usable	Additional Predicted Aircraft Applicable	Skill Criticality	Frequency of practice required for high proficiency & retention	Relative Cost effectiveness of on-board CIG	Relative Applicability for O.B.C.I.C. Implementation	Comments	DCS CORPORATION
Y=Yes N=No M=Maybe (Type)			High Medium Low	High Medium Low	High Medium Low	High Medium Low	*=S=Specific G=General D=Desired R=Required	Key to Symbology
								Air to Air Environment
								Fixed Wing
Y (2D-3D)	HMD	F-18, F-14	High	High	Meduim-High!	Meduim-High	!=very effective candidate for HMD equipped Aircraft	Combat Maneuvering
Y (3D)	HMD	Any with HMD	Medium	High	Low	Low		Air Refueling
Y (3D)	HMD		Medium	High	Low	Low		Formation Flying
	HSI, HUD, HMD	JVX	High	High	High	High		Airborne Threat Avoidance
			High	High	High	High		Air Intercept
								Rotary Wing
		JVX F-18 F-16 F-14	Medium	High	Low	Low		Formation Flight
			Medium	Medium	Low	Low		Airborne Threat Avoidance
								Air to Surface Environment
								Fixed Wing
			High	Medium	Low	Low		Visual Navigation
			High	Medium	Low	Low		Visual Reconnaissance
			High	High	Medium	Medium-High	c=assuming sensor based	Target Acquisition
								Weapons Delivery
			High	High	High	High		Bombs
			High	Medium	High	High		Visually Guided Missiles
			Medium	High	High	High		Gunnery
								Takeoff/Landing (Field)
			High	Low	Low	Low		Day
			Medium	Medium	Medium	Medium-Low		Night
								Takeoff/Landing (Carrier)
			Medium	High	Medium	Medium		Day
			High	High	High	Medium-Low		Night
			High	High	Medium-High	Medium-High	S=Yes-cockpit graphics No-Sensor or outside views	Low Level Flight
			High	High	Medium-High	Medium-High		Low Level Navigation
								Rotary Wing
Y (3D)	HMD or HUD	JVX	Medium	Medium	Low	L for non HMD M for HMD		Visual Navigation
Y (3D)	HMD or HUD	JVX	High	Medium-High	Low			Visual Reconnaissance
Y (3D)	HMD or HUD	JVX	*	High	Medium	Low	*=Low for non-sensored High for sensor eq.	Target Acquisition
Y (3D)	HMD or HUD	JVX AH-1T	High	Medium	Medium	Medium		Weapons Delivery Bombs
Y (3D)	HMD or HUD		High	Medium	Medium	Medium		Visually Guided Missiles
Y (3D)	HMD or HUD		High	High	Medium	Low		Gunnery
Y (3D)			Medium	Medium	Low	Low		Anti Sub Warfare
M (3D)	TAC NAV	CH-53E	High	High	Medium	Medium- Low		Confined Area Manuevering
			High	High	High	High		Low Level Piloting
			High	High	High	High		Low Level Navigation
								Takeoff/Landing (Field)
			Medium	Medium	Low	Low		Day
			Medium	Low	Low	Low		Night
								Takeoff/Landing (Carrier)
			High	High	Low	Low		Day
			Medium	High	Low	Low		Night
		MH-53E	High	High			#=see low level piloting	Mine Sweeping
								Sensory Environment
	MFD	JVX	High	High	Medium	Medium		Radar/Radar Landmass
			High	High	Low	Low		Sonar or Acoustic Sensor
	MFD	JVX AH-1T	High	High	High	High		Forward Looking Infrared
			High	Medium	High	High		TV-Data Link
			High	High	High	High		Electronic Counter Measures

Conclusions

The development and use of on-board CIG based training systems can enhance operational readiness.

Significant benefits from on-board CIG will accrue for the following types of tasks:

- tasks in which g-loading and handling qualities are significant,
- those in which workload in ground-based simulation is unrealistic,
- tasks which should be flown in a simulated high-threat environment,
- practice launching of high-cost, sensor-based weapons under realistic conditions,
- tasks requiring frequent practice to maintain proficiency, and
- a wide range of tasks to be practiced while deployed away from ground training facilities.

Some limitations were found that might prevent application of on-board CIG to some training tasks. The most significant limitations in the near term are the field of view of available displays, and the capacity and routing of existing signal and data paths. Other limiting factors are safety considerations and tradeoffs between cost and image realism. A final consideration is the need for mutually beneficial interaction between operational and training considerations during the development cycle of flight hardware. It is recommended that potential conflicts over scarce aircraft space can be avoided in three ways:

- utilization of existing and planned on-board hardware in training modes,
- development of a training computer image generator as a pod to be mounted temporarily on a weapon station for training missions only,

long term merging of training and tactical considerations in the development phase of new weapon systems and avionics.

SECTION II

Survey of Navy Cockpit Displays

APPROACH

Several methods were used to survey Navy cockpit displays. These included searches of current literature and on-going projects using the Defense Technical Information Center (DTIC) and the Naval Personnel Research and Development Center's Manpower and Training Research Information System (MATRIS). In addition, organizations involved in display development and specification were contacted. These included the Naval Air Development Center, the Naval Air Systems Command, and the Naval Avionics Center. Finally, when necessary, equipment manufacturers were contacted. By means of these contacts and library research at the Naval Air Systems Command, NATOPS manuals and display specifications for most Navy aircraft were compiled. This seemingly straightforward task was complicated by the fact that there is no central Navy repository retaining display specifications for current Navy aircraft. Although all specifications pass through several cognizant Navy organizations en route to final approval, only the latest are retained. In some cases, the equipment manufacturer or aircraft prime contractor was the only available source of copies of the specifications.

DISPLAY SURVEY RESULTS

Present Displays

The results of the survey of present Navy aircraft displays are summarized in Tables 2 through 11 in Volume II. These tables show several groups of information: the displays available on each type of aircraft, the aircraft applicable for each type of display, and display specifications and manufacturers for a number of current aircraft.

Most Navy aircraft have one or more panel-mounted cathode ray tube (CRT) displays. A few have head-up displays (Figure 6), but none presently have helmet-mounted displays, Figure 7, (except F-4 Phantom and AH-64 Cobra aircraft with simple reticles). This is significant because it means that those tasks requiring a large field of view will be impossible on-board the aircraft, except for instances where the real outside scene will

TABLE 2

PRESENT DISPLAYS VS. AIRCRAFT

Display	Aircraft
HUD	F-18
	F-14
	AV-8B
	A-7
	A-4
Multipurpose Display Indicator (MDI),	
or Digital Display Indicator (DDI)	F-18
or Multiple Display Indicator	F-14
	AV-8B
or Indicator Group Display	EA-6B
	A-4 (actually the HUD)
	H-60
	P-3C
	S-3
Horizontal Situation	F-18
Indicator (HSI)	F-14
	F-4
	P-3C
Vertical Display Indicator (VDI),	
or Analog Display Indicator (ADI)	
	F-14
	A-6E
	EA-6B
Tactical Information Display (TID),	
or Tactical Display	
	F-14
	H-60

	P-3C
TACNAV Display	
	SH-3H
	SH-2F
Detail Data Display	F-14
Radar Display, or Radar Scope	
	A-7
	A-6E
	EA-6B
	A-4
	SH-3H
	SH-2F
	F-4
Strobe Display Scope	F-4
Video Display or Video Monitor	
	A-6 (FLIR)
	EA-6B
	A-4 (Walleye)
	S-3 (FLIR)
	P-3C (FLIR)
Panoramic Display	
	EA-6B

TABLE 3

PRESENT AIRCRAFT VS. DISPLAYS

Aircraft	Display (s)
F-18	*Multipurpose Display Indicators (MDI), also called Digital Display Indicators (DDI), left and right *Horizontal Situation Indicator (HSI) *HUD
F-14	Pilot: Vertical Display Indicator (VDI) *HUD Horizontal Situation Display Indicator (HSI) Radar Intercept Operator (RIO): Detail Data Display (DDD) Tactical Information Display Multiple Display Indicator
AV-8B	*HUD Multipurpose Display
A-7	*HUD Radar Scope (can be used in TV mode w/Walleye)
A-6E	*Analog Display Indicator (ADI), also called Vertical Display Indicator (VDI)

*Indicates display specifications are listed in the appropriate table

	Radar Scope or Display
	FLIR Video Display
A-4	*HUD, also called Digital Display Indicator (DDI)
	Radar Scope (Shrike)
	Video Monitor (for Walleye)
H-60	Multipurpose Display, also called Converter Display Unit
	Tactical Display
SH-3H	TACNAV Display
	Radar Display
S-3	Multipurpose Display
	FLIR Video Display
EA-6B	Pilot:
	*Analog Display Indicator (ADI), also called Vertical Display Indicator (VDI)
	Radar Scope/Display
	ECMO 1:
	Panoramic Display
	Video Display
	Radar Scope
	ECMO 2:
	Panoramic Display
	Video Display
	Digital Display Indicator
	ECMO 3:
	Display Indicator
	Digital Display Indicator
P-3C	*Pilot's Tactical Display

*Indicates display specifications are listed in the appropriate table

		Horizontal Situation Indicators (2)
		FLIR Video Monitor
		Indicator Group Display
F-4	Pilot:	
		Radar Scope
		Strobe Display Scope
	Radar Intercept Operator:	
		Radar Scope
		Strobe Display Scope
SH-2F		TACNAV Display
		Radar Display

*Indicates display specifications are listed in the appropriate table

TABLE 4

Aircraft	Manufacturer
*VTXTS	Douglas Aircraft Company/British Aerospace
H-60	Sikorsky
AV-8B	McDonnell - Douglas
A-7	Ling - Temco - Vought
SH-3H	Sikorsky
P-3C	Lockheed
A-4	Douglas
*CH-46	Boeing Vertol
*CH-53	Sikorsky
HNVS configured CH/MH53E	Sikorsky
F-4	McDonnell - Douglas
*JVX	Bell/Boeing (initial lot)
S-3	Lockheed
SH-2F	Kaman
A-6	Grumman
F-14	Grumman
F-18	McDonnell - Douglas/Northrop

*Indicates aircraft which currently do not have displays with the potential for use with computer generated imagery.

TABLE 5

F-18 Display Specifications

I. HUD	
a. Field of View	20° circular centered 4° below design eye waterline
b. Resolution	0.8 ± 0.2 mrad with symbol line brightness of 1000 fL; no greater than 1.8 mrad at maximum symbol brightness
c. Luminance	such that projected images are clearly defined against background of 10,000 fL
d. Contrast	0.20
e. Color	aviation green
f. Temporal	symbol writing refresh rate 60 Hz; phosphor persistence such that a flicker-free display with no symbol smearing is presented
g. Function	real time projection of flight information in symbolic form into pilot's forward FOV; display of attack, navigation, situation, and other steering control information symbology so as to appear at infinite distance to the A/C
II. Horizontal Situation Display (or Indicator)	
a. Field of View	9° by 9° at a 28° downlook from pilot's design eye position along the centerline of the A/C
b. Resolution	56 line pairs per degree subtended both horizontally and vertically
c. Luminance	such that it is readable in an ambient of 10,000 fL; adjustable to 300 fL minimum
d. Contrast	4.88 in 10,000 fL ambient, 6.69 in 6,000 fL ambient; 5.6 shades of grey increasing by $\sqrt{2}$ in intensity

		for 10,000 fL ambient, 6.5 by $\sqrt{2}$ in 6,000 fL ambient
e.	Color	aviation green
f.	Temporal	60 Hz refresh rate; phosphor persistence time (to 10% of maximum brightness) of less than 25 msec presents navigation information in the form of a full color moving map display with CRT generated overlay
g.	Function	provides aircraft altitude, steering, and navigational information with a superimposed projected moving map display.

III. Multipurpose Display Indicators (or Digital Display Indicators): 2

a.	Field of Views	10.4° by 10.4° at a 22° downlook from the pilot's design eye position; 17° to the right and left of the centerline design eye position
b.	Resolution	58 line pairs per degree subtended both horizontally and vertically
c.	Luminance	highlight saturation of not less than 200 fL; sufficient for both dark and 10,000 fL ambients
d.	Contrast	5.67 in 10,000 fL ambient, 8.09 in 6,000 fL ambient; 5.6 shades of grey increasing by $\sqrt{2}$ in intensity for 10,000 fL ambient, 6.5 by $\sqrt{2}$ in 6,000 fL ambient
e.	Color	aviation green
f.	Temporal	60 Hz refresh rate; phosphor persistence time (from 100 to 10 fL) not greater than 25 msec
g.	Function	left indicator used primarily for stores status, built-in test status, engine monitor, caution, and advisory displays; right indicator normally used for radar and weapon video displays

TABLE 6

F-14 Display Specifications

I. HUD

a.	Field of View	20° circular
b.	Resolution	1.3 mrad maximum at 3000 fL
c.	Luminance	3000 fL minimum; such that projected symbols are discernible against 12,000 fL background
d.	Contrast	- - -
e.	Color	- - -
f.	Temporal	50 Hz frame repetition rate
g.	Function	presents flight information on the pilot's windscreen focused at infinity and superimposed on the real world

TABLE 7

A-6 Display Specifications

I. Analog Display Indicator

a.	Field of View	5.2 inches vertical by 7.0 inches horizontal usable display
b.	Resolution	60 lines per inch vertical by 79 lines per inch horizontal
c.	Luminance	minimum of 500 fL; such that usable in 10,000 fL ambient .29; six shades of grey increasing by 1.4 in brightness
e.	Color	green
f.	Temporal	60 Hz refresh rate; phosphor persistence such that a flicker-free display with no symbol smearing is presented
g.	Function	generates and displays artificial ground and sky texture which meet to form the reference horizon; viewing area of 30° in elevation and 50° in azimuth

TABLE 8

A-7 Display Specifications

I. HUD

a.	Field of View	20° circular centered 3.7° below the optical reference axis
b.	Resolution	1.0 $\pm$ 0.3 mrad at 1000 fL in brightness
c.	Luminance	minimum of 1600 fL; such that projected images are clearly defined against background of 10,000 fL
d.	Contrast	- - -
e.	Color	P-1 phosphor (green)
f.	Temporal	- - -
g.	Function	projects flight information, in symbolic form, into pilot's forward field-of-view

TABLE 9

A-4 Display Specifications

I. HUD

a.	Field of View	20° circular at eye level
b.	Resolution	1 ± 0.3 mr with symbol brightness at 1,000 fL
c.	Luminance	such that generated symbols are visible against a 10,000 fL background
d.	Contrast	- - -
e.	Color	P-1 phosphor (green)
f.	Temporal	50 frames/second nominally; 33 frames/second under worst case computation conditions
g.	Function	to display aircraft performance information symbology, such as altitude, velocity, altitude, and heading, in the pilot's forward field of view and focused at infinity

TABLE 10

AV-8B Display Specifications

I. HUD

a.	Field of View	20° circular centered 7° below the design eye waterline
b.	Resolution	0.8 ± 0.2 mrad with symbol line brightness of 1,000 fl; no greater than 1.4 mrad at maximum line brightness
c.	Luminance	such that projected images are clearly defined against background of 10,000 fL
d.	Contrast	0.20; 3 shades of grey
e.	Color	aviation green
f.	Temporal	symbol writing refresh rate 60 Hz; phosphor persistence such that a flicker-free display with no symbol smearing is presented
g.	Function	real time projection of flight information in symbolic form into pilot's forward FOV; display of V/STOL, navigation, attack, situation, and steering control information symbology so as to appear at infinite distance to the A/C

II. Multipurpose Display

a.	Field of View	5 by 5 inch CRT to the left and below the HUD
g.	Function	navigation, radar warning, stores status, weapons, REST, BIT, and summary checklists displays

(Remaining specifications are similar to F-18 MDI)

TABLE 11

HNVS CONFIGURED CH/MH53E
DISPLAY SPECIFICATIONS (PLANNED)

I. Integrated Helmet and Display Sight System (IHADSS)

a.	Field of View	$30 \pm 1^{\circ}$ VFOV by $40 \pm 1^{\circ}$ HFOV w/ 10% corner obscuration, 1:1 mag. $\pm$5% distortion
b.	Resolution	(TV lines/Raster height, MTF) on axis: (10, .84) (100, .73) (200, .59) (400, .36) (600, .14) off-axis 1/2 field radial & tangential: (10, .84) (100, .70) (200, .55) (400, .26) (600, .08)
c.	Luminance	4 fL min. to 150 fL max.
d.	Contrast	8 shades of grey (in 2 increments) at 4-10 fL w/max scene illuminance of 0.1 lum/m^2
e.	Color	P43 (Green)
f.	Temporal	Refresh rate of 60 Hz with 2:1 interlace, 525 or 875 line rates automatically adjusting to match inputs
g.	Function	Target acquisition and designation, and night vision for pilotage

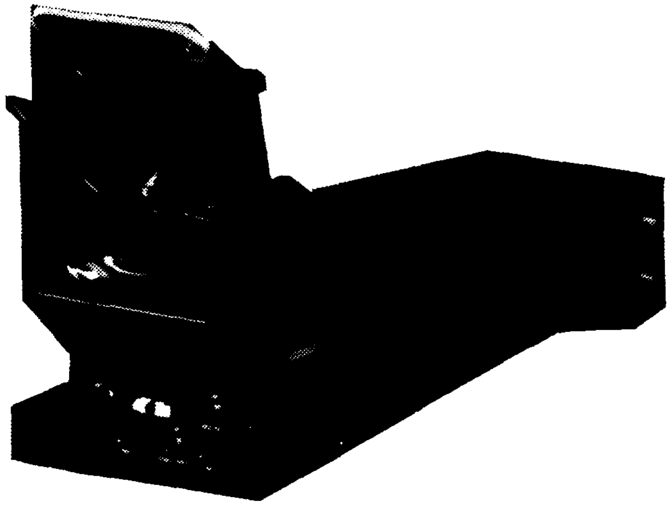


Figure 6. Example of a Head Up Display (HUD), which allows concurrent viewing of informational symbology and the outside scene (photo courtesy of General Electric Co.)

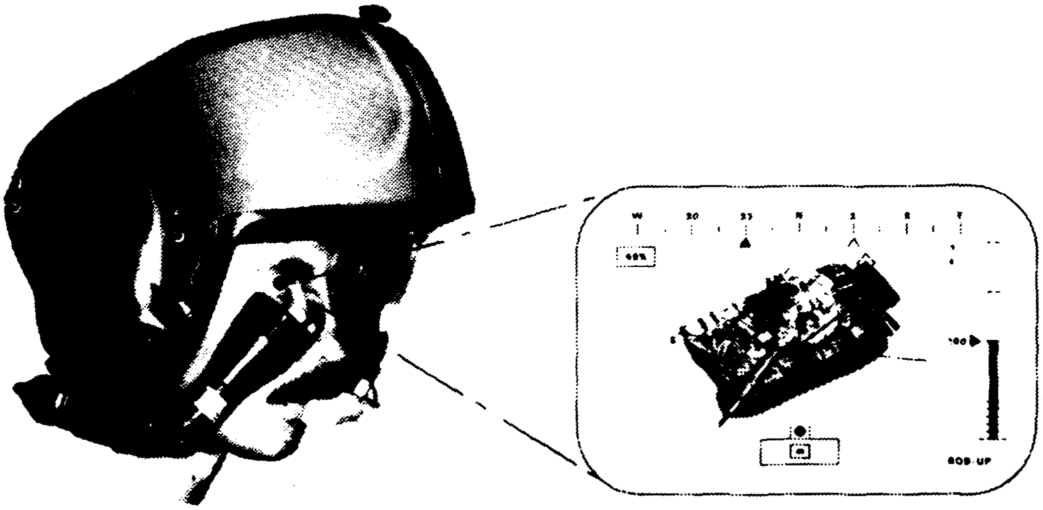


Figure 7. Example of a Helmet Mounted Display, such is planned for the for the CH/MH53-E (courtesy of Honeywell, Inc.)

serve the purpose. Examples of such tasks are formation flight, display of artificial air targets during air combat maneuvering, and visually based low level flight.

Planned Displays

At the time of this report, no new Naval aircraft displays were in the formal planning cycle. Thus, all displays fall either into the "present" or "predicted" categories.

Predicted Displays

The last category contains, "predicted displays", the full gamut of displays that may eventually be used in the Navy aircraft, but are neither formally planned nor presently used. At one end of this category are fairly near term displays soon to enter the formal planning cycle. The other extreme comprises display technologies not yet mature which are potential candidates for future cockpits. Several new aircraft or modifications to older aircraft are presently being developed. Since the display specifications for these aircraft are not yet finalized, these must fall into the category of predicted displays. Examples are the A-6E Upgrade, CH/MH-53E, JVX and F-14D.

For the A-6E Upgrade the displays will include five panel-mounted, multi-function displays (see Figure 1) of 5 inch diagonal. These will be common with the F-18 and F-14D. It is planned to have a MIL-STD-1553 bus. A head-up display is under consideration. The A-6E will not have a helmet-mounted display system.

The F-14D is expected to contain the same displays as the A-6E Upgrade.

The CH/MH-53E is a helicopter system which will include the Helmet Mounted Display (HMD) developed by Honeywell and Martin-Marietta for the Army AH-64 and referred to as the Integrated Helmet and Display Sight System (IHADSS) (Figure 7 and Table 10) or as the Target Acquisition and Designation System/Pilot's Night Vision System (TADS/PNVS). This system will display a head-slaved 40-degree field of view containing a combination of raster-scanned FLIR imagery and calligraphic symbology. The aircraft will incorporate a record/replay capability for these displays.

The JVX program has not yet finalized the display selection. Some of the displays under consideration are: a dual helmet-mounted site or display, four panel-mounted monochrome or color multi-function displays, an Aviator's Night Vision Imaging System (ANVIS) comprising 3rd generation night vision goggles with an electronically generated reticle, and a digital map. A dual 1553B display bus is anticipated.

In addition to these specific aircraft upgrade programs, several trends in cockpit displays will ease the development of on-board CIG training applications. Foremost among these is the integration of displays with an architecture containing a common data bus and a common video bus. Combined with the trend toward multi-function displays, this should make integration of CIG systems into newer aircraft simpler than in older aircraft in which each display had its own input source. The F/A-18 is an example of this approach, which will be followed by other aircraft expected to enter the inventory, such as the A-6E Upgrade and F-14D. The use of such multiple, interchangeable displays allows one or more items to be devoted temporarily to training imagery while maintaining all basic flight information.

Other technologies are currently approaching the stage of development wherein they may be considered for application to future cockpits. They include color CRTs (shadowmask and other technologies), holographic wide field of view head-up displays (20 deg. by 30 deg.), and (more remote) helmet mounted displays for fixed wing aircraft. Such helmet-mounted displays can be expected to have a 10 to 12 degree field of view initially, with expanded field of view requiring significant additional development. In the more distant future, one can expect various types of projection and flat panel displays. These trends will be driven by two factors in addition to the usual "technology push." These factors are: the need for smaller fighter aircraft with less cockpit real estate available for displays, and the desire to match the human operator's need for wide field of view at one-to-one magnification. Some future display technologies that may eventually enter Navy aircraft cockpits are described in Table 12. It should be noted that any technologies in the initial stages of development cannot be expected to appear in operational aircraft cockpits until the mid to late 1990's or beyond. Technologies presently ready to enter cockpits will not appear in operational aircraft until 1989 to 1990 at the very earliest.

TABLE 12. ADVANCE DISPLAY TECHNOLOGY TABLE

DISPLAY	FIELD OF VIEW	RESOLUTION	LUMINANCE	CONTRAST	COLOR	TEMPORAL
Liquid Crystal (LCD)	10-80°	Very High 5 pixel/mm matrix addressed 40 l/mm beam scanned.	Reflective mode device	Excellent in high ambient light. 10 Readable in Ambient light of 100K lumen/m^2 or more better than LED's in high ambient. Needs illumination in low ambient.	Monochrome colors with use of filters or dye	Slow Display (.1 sec) Temperature affects speed. A possible non-returnable memory.
Gas Discharge (Plasma) AC	180°	Good 3.3 pixel/mm 1024 x 1024 cells	Limited 200-300 cd/m^2	Good 1.0	Monochrome Red-Orange	Fast
Gas Discharge (Plasma) DC	100-120°	Limited to 2.5 Lines/mm	Limited 100-150 cd/m^2	Good 1.0 Inadequate in sunlight	Monochrome Orange-Green	Fast
Color CRT	Not applicable	up to 2040 x 2048 pixels (5" x 5" to 8" x 8"	Red 514 cd/m^2 Green 1130 cd/m^2 Blue 205 cd/m^2	Sun readable	Full color	Green (P-43) 1.2 millisec Red and Blue (P-22) (10 sec - 1 millisec)

DISPLAY	FIELD OF VIEW	RESOLUTION	LUMINANCE	CONTRAST	COLOR	TEMPORAL
Electro-Deposition EDD		10 lines/mm	Reflective Mode Device	Good		Slow .05-.3 sec
Electro-Phoretic	Wide	Good 5 lines/mm	Reflective Mode Device Better Than LCD	Very High 40:1	Any Two	Slow .01 sec
Incandescent	Moderate	Poor	Good	Good	Use Filters	Moderate to Slow
Fiber-Optic	Very Small		Dependent on Brightness of Source	Good	Use Filters	Fast
Vacuum Fluorescent	70^{o}	Very High 5 Pixel/mm Displays of 250 x 250 available	Typical 700 cd/m^2 if filtered for green 200-300 cd/m^2 There is a potential for 15000 cd/m^2	1	Monochrome Colors with use of filters	Used at TV Rates

DISPLAY	FIELD OF VIEW	RESOLUTION	LUMINANCE	CONTRAST	COLOR	TEMPORAL
Light Emitting Diode (LED)	$\pm 45^{\circ}$ Head-Down Flat LED 180°	Very Good 25 pixel/cm Possible 5 pixel/mm	4:1 35,000 cd/m^2	4:1	Monochrome Green, yellow Red.	2×10^{-3} sec/cycle
Electro-Luminescent AC Powder	$140\text{-}180^{\circ}$	5 pixels/mm Small HMD Displays with 20 pixel/mm	Poor 60-400 cd/m^2	Good with filters 10:1	Depends on Phosphor all possible needs development	Standard Video Rate Compatible
Electro-Luminescent DC Powder	$140\text{-}180^{\circ}$	5 pixels/mm	Poor 60-400 cd/m^2	Fair	Several	Standard video rate Compatible
Electro-Luminescent AC Thin Film	$140\text{-}180^{\circ}$	4 pixels/mm & 200 lines/ch	Very Good 340 cd/m^2	3:1 Readable in 10^5 lumen/m^2	Monochrome	6.7×10^{-6} sec/cycle
Electro-Luminescent DC Thin Film	$140\text{-}180^{\circ}$		Low		Several	6.7×10^{-6} sec/cycle

DISPLAY	FIELD OF VIEW	RESOLUTION	LUMINANCE	CONTRAST	COLOR	TEMPORAL
Ferro Electric PLZT	Trans-mission Device or Projection device	40 lines/mm	Poor Not for Air-craft reflective mode operation		No Trans-mission Device	Fast $10^{-6} - 10^{-5}$ sec
Ferro Electric KDP	Trans-mission device or projection device	900 pixels/line	1000-4000 lumens	High	No trans-mission Device	Fast operate at TV rates
Magneto-Optic	Trans-mission device or projection device	256 x 64 pixels	suitable for daylight	Very High 20:1	No trans-mission device	$10^{-4} - 10^{-3}$ sec/point address rate
Magnetic particle	Wide	3 lines/cm	Reflective mode device	Very High 15:1	BW	Write speed $= 10^{-6}$ sec non-volatile

DISPLAY	FIELD OF VIEW	RESOLUTION	LUMINANCE	CONTRAST	COLOR	TEMPORAL
Electrochemical Electrochromic ECD	Wide	1 line/mm	Reflective mode device	High 5:1	Limited	Slow 0.1 sec
Conventional Cathode-Ray Tube	Wide	$25.4\text{-}381 \times 10^{-6}$ m Spot size 3.15 lines/mm	60-200 cd/m^2	4:1 @ 10K FtL 8:1 @ 5 FtL	Color with shadowmask or penetration any color	Fast 1×10^{-7} - 3×10^{-7} sec/cycle at standard video frame rates. As short as 1×10^{-9} sec/cycle possible.
Flat Face Cathode-Ray Tube	Wide	Poor Focus and geometrical distortion	Good	High	No	Fast
Digitally Addressed Cathode-Ray Tube	Wide	512 char[illegible]ter 135 mm [illegible]5 mm with 7 x 5 char.	820 cd/m^2	High	No but being developed	Fast
Dark Trace Cathode-Ray Tube	Wide	Good Similar To conventional CRT.	Requires separate illumination	Very Good	No	Slow

Display Survey Conclusions and Implications for on-board CIG

At present, the number and type of tasks which could be trained with on-board CIG is limited by available displays. Thus, all weather/night operating aircraft are the best platforms for on-board CIG since all of their operations can be based upon the available displays without resorting to the out-of-cockpit view.

Current aircraft may additionally be limited in the data and video paths available for interfacing to the on-board CIG. Availability of data paths may strongly influence the selection of aircraft for on-board CIG application. A detailed examination of this problem was beyond the scope of this study.

The lack of wide field of view displays restricts on-board CIG training of low-level flight at altitude to those few aircraft having helmet-mounted displays (e.g., CH/MH-53E), and all-weather, night-flying aircraft which can fly at low altitude based solely upon cockpit displays (e.g., A-6E).

Air combat training techniques are also limited by available displays. For example, while air intercept training is feasible using HUD and panel-mounted displays, air combat maneuvering is not well served by such displays. This results from the pilot's need to maintain visual contact with the opponent(s) over a wide field of view. Thus, in order to benefit from energy/maneuverability diagrams, they would need to be displayed on a helmet-mounted display. This has been successfully done experimentally by the Naval Air Development Center (NADC). The installation of such a display for training purposes (perhaps in a limited number of trainer aircraft) could prove quite useful.

As will be discussed below in the section on training possibilities, the training of missile envelope recognition is needed. In order to practice the range recognition portion of this task with artificial targets, it is desirable to display the targets with the correct contrast as well as size. This will pose a problem for the display, since it normally has no information regarding the background luminance. Thus, for this training task, a background luminance sensor would need to be installed or interfaced with the CIG and display systems to allow automatic contrast adjustment.

The over-all conclusion from the display survey is that a significant set of training tasks can be accomplished with available cockpit displays. The number and type of tasks trainable with on-board CIG is largely limited by available cockpit displays and by existing data paths. A detailed study of interfacing techniques is therefore recommended.

CIG Technology Survey

APPROACH

A wide range of vendors of computer-image generation systems was contacted to solicit information about present systems as well as planned and predicted developments in the technology. In addition, a literature search was performed. This survey is unique in that it covered computer-image generation equipment vendors in what were previously thought to be non-overlapping markets. The survey was not limited to ground-based simulation visual system manufacturers, but also included real time avionics and avionics development equipment vendors.

RESULTS

General Conclusions of the CIG Survey

Limitations posed by factors such as interfacing and display availability were found to be far more fundamental than CIG limitations. Hence these factors will largely determine the direction to be taken by on-board CIG developmen. They will also drive selection of applicable airframes.

One of the significant conclusions of this survey is that the problem of developing an airworthy CIG system of respectable capacity is one of the least limiting factors in the overall development of on-board CIG training. This does not mean that the development effort has been concluded; because this undertaking is neither complete nor trivial. Significant work remains to be done, but no significant impediments to the development of such a system are forseen. Indeed, several such systems are already under development as will be discussed later in this report.

An additional reason why CIG development will not be the limiting factor stems from the broad range of demands placed upon the CIG system. These range from quite simple two-dimensional symbology to realistic high-resolution, three-dimensional sensor images. At the low end of this spectrum of needs, present avionics equipment is already able to fulfill the requirements. An example is the General Electric Integrated Flight and Fire

Control System (FIREFLY), which has already undergone flight testing and possesses the capability to generate artificial ground and air targets.

At the high end, the latest technology would be challenged. An on-board CIG system can be designed to meet many if not all of these needs. Since success of the program is not predicated upon meeting the most difficult requirements in this spectrum, the program can succeed despite CIG limitations. Training tasks compatible with minimum CIG capability should not be forsaken in the pursuit of the more difficult ones. One such opportunity that should not be missed is the chance to include on-board training modes in the new INEWS threat warning system about to be developed. It is recommended that the full spectrum be addressed, including both low and higher risk goals.

Two sets of vendors (avionics and ground simulation) were found to be taking converging paths from quite different starting points toward a remarkable similarity in products, architectures, and purposes. Any development of on-board CIG systems must certainly account for the possibility that successful contenders could come from either group. A few firms have departments or divisions in both groups (General Electric Co., McDonnell Douglas Electronics Co., Hughes Aircraft Co.); however, they do not yet appear to have taken advantage of the potential synergism.

<u>Specific Results of the CIG Survey (Avionics)</u>

The flight worthy CIG systems are presently under development for operational purposes. They fall into three general categories. These are digital maps, pictorial graphics, and firecontrol systems including simple graphic symbology. In each case, the systems being developed for operational applications may also be suitable for use in training modes. Each of these types of systems will be treated in turn.

Several digital map generation systems are currently under development. Vendors developing such systems include Hughes Aircraft Co. (Airborne Electronic Terrain Map System-AETMS for the Air Force), Harris Corp (Digital Map Generation-DMG for AFTI F-16), Texas Instruments, and Collins. As illustrated in Figures 8-10, these systems display plan and perspective views of terrain based upon Defense Mapping Agency (DMA) digital data. They are intended to aid all-weather navigation and to replace the present generation horizontal situation displays based upon film strip technology. One such

Figure 8. Perspective Shaded Relief Image

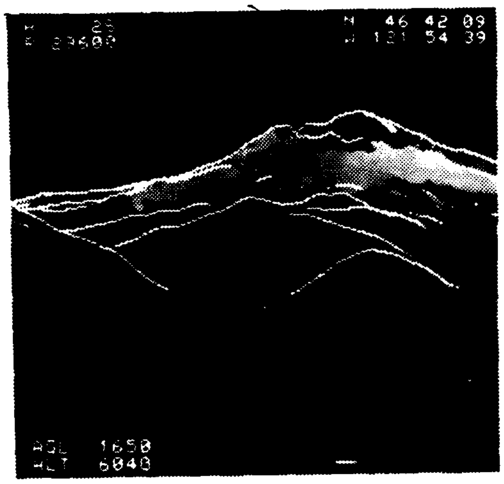


Figure 9. Perspective Shaded Relief Image with enhanced ridge lines

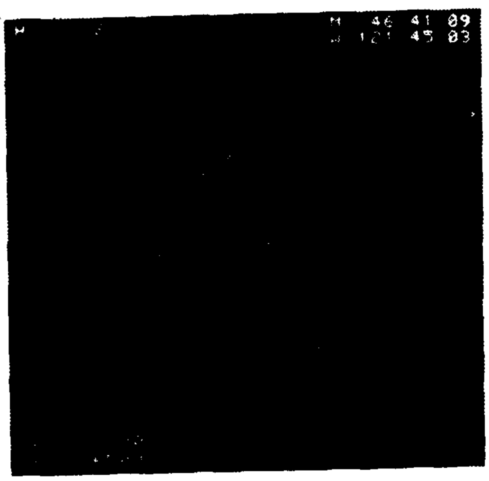


Figure 10. Plan View Shaded Relief Image. Figures 8-10 represent computer generated images produced by the Airborne Electronic Terrain Mapping System (AETMS) (courtesy of Hughes Aircraft Co.)

system weighs 25 pounds and takes up a volume of .24 cubic feet plus power supply or roughly less than .48 cubic feet total. It consumes 300 watts of power and has a computational capacity of 44 million operations per second (MOPS).

The trend toward incorporation of advanced graphic capabilities into cockpits is exemplified by the Gaertner System illustrated in Figures 11-13. This system can generate up to 10,000 polygons and fits in a standard ATR box (volume = 0.82 ft.). As with many of the present generation of computer image generators, it has a parallel processor architecture. Such systems are generally intended to provide aircraft control and system management displays. An Air Force program is developing "Pictorial Formats" for such displays. The intent is to provide quicker, more natural information transfer to the pilot than is possible with conventional gauges, dials and alphanumeric displays. Typically, color displays are used in these developmental systems.

The Naval Air Development Center is planning to develop a computer image generation pod to test and demonstrate advance control displays. The pod will produce graphics of moderate complexity such as a channel flight path. Such a pod could also be used as a test bed for some on-board CIG training techniques.

The last category of present flightworthy CIG systems is the fire control displays. Representative of these are two systems developed by General Electric Company, FIREFLY and AIMGUNS. The FIREFLY system is an integrated flight and fire control (IFFC) system. Of interest for the on-board CIG program is its capability to generate artificial air and ground targets and present them on a head up display. These targets are composed of simple symbology. The AIMGUNS system, shown in Figure 5, is designed to improve aiming ability, as its name implies. Its interesting characteristic from a training standpoint is a feature called "bullets at target range." This system, when flown against a real target, generates a circular symbol in the head up display at the location where the bullets would pass through the target range.

The Goodyear Associative Processor (ASPRO) is a further example of the state of the art in on-board computational technology. This is a parallel processor architecture comprising 1,792 processors. It can perform 40 MOPS, weighs 37 pounds, uses 200 watts of power, and is contained in a volume of 0.44 cubic feet. The ASPRO is being used on

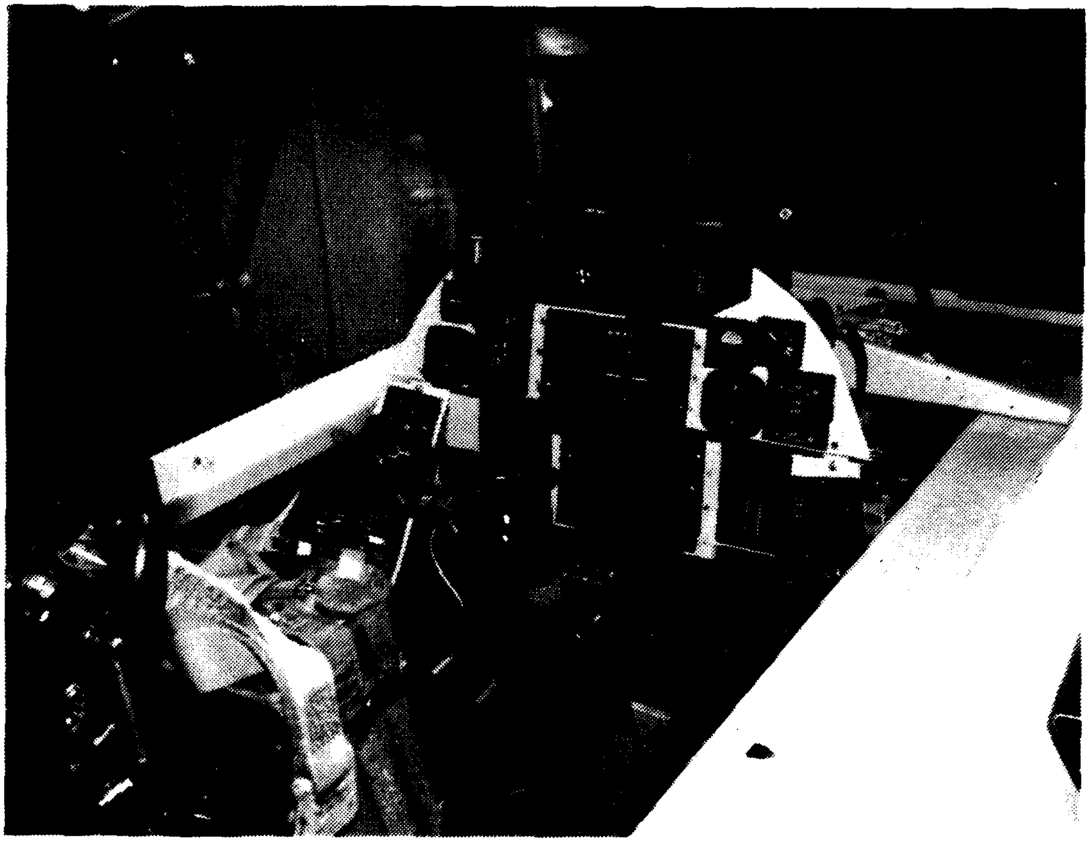


Figure 11. F-14 Simulator Cockpit at the Naval Air Development Center showing two computer generated panel displays. Figures 11-13 courtesy of W. W. Gaertner Research, Inc.)

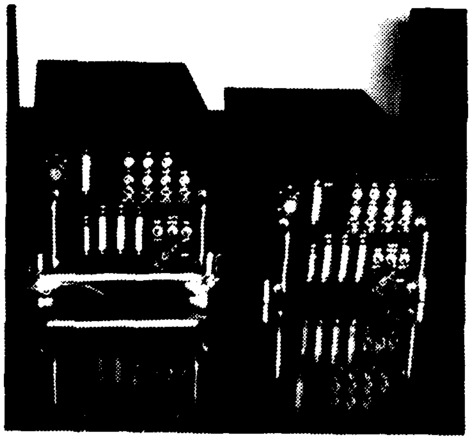


Figure 12. Flight Worthy Graphics Generators used to Create the Images shown in Figure 11.

Figure 13. Sample Threat Warning Display Generated by Equipment Shown in Figure 12.

the E-2C aircraft to display a large number of targets. For test purposes a second ASPRO is used to simulate a large number of target inputs to the ASPRO under test.

As discussed in the training section of this report, various training needs can be addressed by each of a wide variety of computer generated image fidelity levels. These range from simple symbology to realistic representations of the real world. Thus it can be seen that the concept of on board use of CIG could hardly fail for lack of CIG capability since several useful levels of capability already exist. On the other hand, a system developed specifically for training purposes could significantly expand the scope of tasks trainable.

Specific Resul⁺⁻ ɔf the CIG Survey (Ground Based Simulation)

Ground-based visual simulation technology today is rapidly advancing toward a goal of higher pictorial fidelity. Because of the proprietary nature of development activities in this fast-moving industry, it would not be prudent to make comparisons of specific systems here. The specifications of current systems are well known, while future developments are competitively sensitive. Thus, the results of the CIG survey will be presented in general terms representative of current development trends. The results, however, are based upon facts supplied by the various vendors.

The term "on-board CIG" need not refer only to in-flight usage. It also can refer to aircrew training on-board carrier ships. Two current ground-based developments relate to this sort of application. One is an approach to flight simulation developed by Rediflight Inc., and referred to as "TRIAD".

In the TRIAD concept, an aircraft is placed in a simulated environment comprising several juxtaposed television projection screens and a high power sound system. (See Figures 14 and 15). Then the aircraft is connected to a computer system that drives it as though it were a flight simulator. If space were available, such a system could be carried on an aircraft carrier.

A more compact approach giving a wider total field of view would be the use of a helmet-mounted simulation display, such as shown in Figure 16. It would be feasible to modify the software in the computers existing in an aircraft such as the F-18 to make the

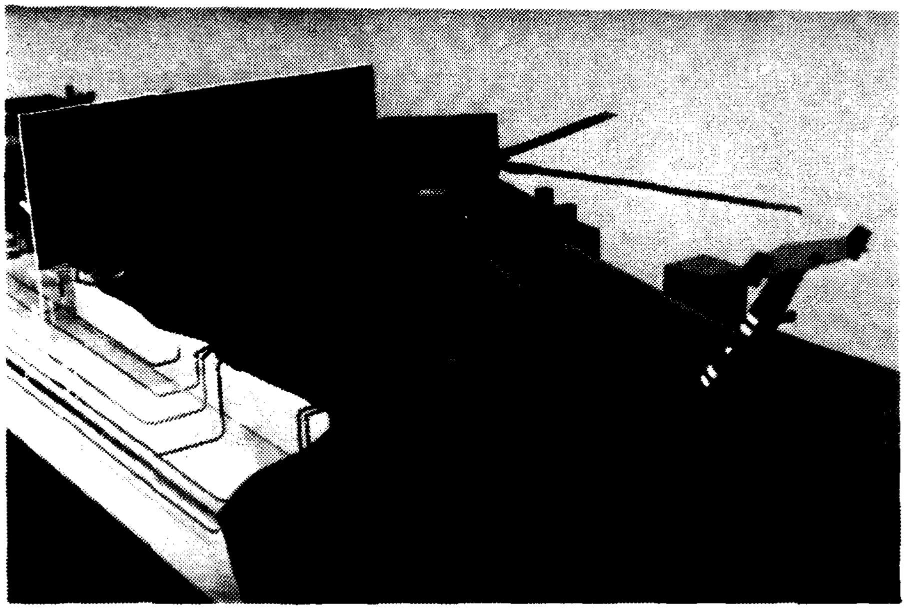


Figure 14. A model of the triad simulation concept using an actual helicopter, temporarlly connected to a computer, to act as it's own simulator. A computer generated view of an outside scene is displayed by three television projection systems

Figure 15. Instructior's view of the system shown in Figure 14
(Figures 14-15 courtesy of Rediffusion Simulation, Inc.)

Figure 16. Breadboard Stereo Helmet Mounted Computer Generated Image Simulation System (courtesy of McDonnell Douglas Electronics Co.)

system temporarily perform its own simulation. Unfortunately, the aircraft modification approach has some drawbacks. A great deal of assembly language software would have to be modified leading to a fairly expensive development effort applicable only to a single aircraft model. Second, the time to convert the aircraft from operational to simulator mode could be as long as several hours. The same would be true for converting back. Built in test routines would need to be run to assure that the aircraft was operationally sound each time the modification was made and reversed. This is one reason for the extensive conversion process. Such flags as weight-on wheels, for instance, would have to be modified for the simulation so that the plane would acknowledge that it was in flight when it was actually on the deck. Perhaps a hybrid approach is possible wherein helmet mounted displays would be used with a separate computer outside the aircraft providing the aircraft simulation/stimulation instead of using the aircraft's own computers for simulation.

The size and weight of a representative range of present ground based and airborne CIG systems can be compared with that of typical missiles that might be replaced by a CIG pod. From Table 13 it can be seen that drastic size reductions would not be required, although repackaging would be necessary. The Maverick missile at 462 pounds and a volume of 6.3 cubic feet is about the largest size for useful comparison, considering current CIG packaging technology. This missile is a 97 inch long cylinder one foot in diameter. For comparison, the Silicon Graphics "IRIS" system weighs only 97 pounds and takes up 3.3 cubic feet, yet it is packaged for commercial, ground based application. Its capacity is approximately 540 polygons each 30th of a second. The power typically available at a weapon station is 2.5 to 6 kVA at 400 Hz and 115 volts.

A variety of techniques is available to reduce the size, weight, and power requirements of CIG systems as well as to achieve the desired geometrical shape. Relatively well established techniques include the following:

- Rigid-flex printed circuit boards,
- Multi-layer printed circuit boards,
- Multi-wire boards,
- Hybrid circuits,
- Leadless chip carriers, and
- CMOS integrated circuits (chips)

TABLE 13. COMPARISON OF SOME COMPUTER GRAPHICS SYSTEMS TO TYPICAL MISSILE WEIGHTS AND VOLUMES

	Weight	Volume	Power	Capacity
Maverick Missile	462 lb.	6.3 ft^3	115V 3Ø 400 HZ 600-3000 Vamps	N/A
Harpoon Missile	1,160 lb.	12.5 ft^3		N/A
Boeing, DARPA Image Generation	3,500 lb.	166 ft^3	18 kVA	1 million pixels/sec (depth buffer). Approx. 367 triangles/30th sec with texture mapping
* Harris (DMG)	25 lb.	.48 ft^3	300 W	44 MOPS
Trillium	300 lb.	24.0 ft^3	2.4 kVA	250k-500k edges
* ASPRO	37 lb.	.44 ft^3	200 W	40 MOPS
* Gaertner	16-22 lb.	.82 ft^3	920 Vamps	10,000 polygons plus symbology
Silicon Graphics IRIS	97 lb.	3.3 ft^3	770 W	540 polygons/30th sec

*Flight worthy packaging
(Others are ground based systems)

Other, more exotic techniques include wafer scale integration, and the products of the Very High Speed Integrated Circuit (VHSIC) program. A rigid flex circuit is one long printed circuit board containing flexible sections at intervals. The board is literally folded to form a very high packing density. This technology is used, for instance, in the HARPOON missile. A hybrid circuit is a single large substrate containing several unpackaged chips along with some ancillary circuitry. Much higher packing densities can be achieved with these than with typical dip packages. CMOS integrated circuits can be used to reduce power requirements substantially.

Training Needs & Techniques

GENERAL DISCUSSION

This section of the report treats a selection of potential training tasks and assesses the relative suitability of each for on-board CIG application. The suitability is based upon a number of factors. These include: criticality and retention of the skills to be trained, estimated relative development and implementation costs, display availability, and required CIG capability.

The results are summarized in Table 1. In this table, the range of display requirements is presented by listing the types of displays that may usefully be applied, each followed by a letter "R" or "D" in parentheses to designate, respectively, whether that type of display is "Required" or "Desired." Similarly, Computer Image Generation requirements are followed, in parentheses, by designation of a particular level as required or merely desired. The CIG requirements are grouped into three major categories: Symbolic, Graphic, and Realistic. These groupings were chosen to represent significant qualitative differences between groups, although it is recognized that there are many gradations among and within the groups.

For our purposes, the groupings are defined as follows:

Realistic - Intended to closely resemble some real object, either as viewed with the eye or as viewed with a sensor system. To the extent that motion of the object can be detected in the training situation under consideration, that motion will be accurately represented.

Symbolic - Not intended to be a pictorial representation of anything. For example, a target represented as a ring or cross on a display.

Graphic - A representation between realistic and symbolic. In this mode, a target might be represented as a cartoon-like drawing (line or filled).

Within the Graphic category, distinction is drawn between two-dimensional (2-D), three-dimensional (3-D), and three-dimensional stereo. Examples of each category (except stereo) are presented in Figures 1, 3, 4, and 13 (2-D) and Figures 2, 5, 8, 9 and 10 (3-D). For our purposes, the term two-dimensional display refers to one wherein any apparent motion of the objects displayed occurs only in the plane of the display. In a three-dimensional non-stereo display, an object may have motions out of the display plane (for example, a ground target). These three dimensional motions are transformed to the equivalent two dimensional motions in the display plane. Three dimensional stereo images require separate presentation to each eye.

The next subsections describe the on-board CIG training potential of a number of specific training tasks. Each training task is discussed in order to further elaborate the results presented in Table 1. The task criticality and frequency of practice required were determined by interviewing experts in each case. These included test pilots, who have commanded or trained similar missions, and personnel responsible for generating system specifications for some of the aircraft involved. The overall applicability for each task is based upon combination of all the factors in the table.

AIR-TO-AIR COMBAT TASKS

Fixed Wing Aircraft

Combat Maneuvering - Combat maneuvering training would be an excellent candidate for computer-generated image training if appropriate displays were available, since it requires exploration of the limits of the aircraft maneuvering envelope. (See Figure 3, 4a, and 4b.) Thus, the g forces that are not well simulated in ground-based trainers are critical to this task. Positive training effects were found during test flights by NADC of a helmet-mounted display showing a very simplified energy-maneuverability envelope. Novice pilots were quickly brought up to performance levels of more experienced pilots

with this technique. Unfortunately, the technique requires the use of a helmet-mounted display, and no present Navy aircraft has one (except the F-4, which has a helmet sight only capable of displaying a reticle and simple cueing). However, development work continues on helmet displays, and combat maneuvering training will become a prime candidate for on-board CIG at such time as these displays appear in operational or trainer aircraft.

In addition to using helmet mounted displays, training techniques are available for use on Head-Up Displays (HUDs). In fact, several such techniques are available using the latest avionics equipment, which may enter service with the next generation of aircraft modifications, such as the F-14D. For example, General Electric's Integrated Flight and Fire Control System (FIREFLY) has been tested on an F-15 in a mode utilizing an artificial target displayed on the HUD. Another system referred to as "AIMGUNS" (Figure 5), utilizes a real target but displays artificial "bullets at target range" to provide scoring feedback to the pilot. These are both tools with excellent training potential.

Air Intercept - Since air intercept operations are generally performed at long range using targets represented symbolically on the aircraft displays (usually based upon radar data), such displays could be artificially generated allowing for greatly increased practice. Thus, only the normal HUD and panel-mounted displays are required with symbolic or graphic images. This is an excellent application for on-board CIG.

Formation Flight - This is not a good candidate for on-board CIG for several reasons. Although it is a skill of moderate criticality requiring frequent practice, such practice is indeed available as a byproduct of normal flight operations. In addition, short of having a helmet-mounted display, no available aircraft displays have sufficient field of view to be adequate for formation flight training. Were one to provide such training, the CIG requirements could range from a minimum of a simple point or points of light representing the other aircraft at night to a maximum of elaborate, detailed daytime representations of the other aircraft, including many specific cues.

Air Refueling - Here again, helmet-mounted displays would be required. When such displays become available, this training task may become a suitable candidate for application of on-board CIG. The reasons are that air refueling normally receives less practice and is more dangerous than simple formation flight.

Airborne Threat Avoidance - This is a critical combat task for which present training opportunities are limited. Ideally, the pilot should be presented with progressively more difficult threat situations. Displays are not limiting for this task, since in normal operation most of the visual threat information is displayed symbolically on the aircraft displays. The only exception is the outside-the-cockpit view of missile launches. However, even without the capability to display the out-of-the-cockpit view, the bulk of the necessary training can be obtained by appropriate simulation (or stimulation) presented on the in-cockpit displays. This, in summary, is an excellent on-board CIG candidate. Some work along these lines is already being undertaken by Teledyne Brown under the title "Phantom Range".

Rotary Wing Aircraft

Formation Flight - As with fixed wing formation flight, and for the same reasons, rotary wing formation flight is not a good candidate for application of on-board CIG.

Airborne Threat Avoidance - Few Navy rotary wing aircraft presently train for avoidance of airborne threats. This may change in the future. Nearly all such aircraft carry rails upon which anti-aircraft missiles could be mounted, although this is not the current practice. If they did train for such tasks, the procedure would be to respond to a visually acquired threat and/or a warning tone with an appropriate, properly timed flight maneuver. Such maneuvers would require moderate practice, but little role for on-board CIG is seen for this task.

AIR-TO-SURFACE WEAPON DELIVERY TASKS

Fixed Wing Aircraft

Visual Navigation - This task is a poor candidate for on-board CIG, since visual navigation requires display of the outside world over a very wide field of view, and since available aircraft displays and even predicted near-term helmet-mounted displays for fixed wing aircraft do not meet this requirement. On the other hand, sensor based navigation does not have these drawbacks and is a good potential candidate. This is discussed further in the section entitled "SENSOR ENVIRONMENT".

Visual Reconnaissance - This is an even poorer choice than Visual Navigation, since it has the same problems and in addition requires a highly realistic image. Again, the drawbacks do not apply to sensor based reconnaisance except that the high degree of realism required would be costly.

Target Acquisition - Although visual target acquisition would have the same problems described above for Visual Reconnaissance and Navigation, these problems do not all apply for sensor-based target acquisition. (See Figures 17 and 18). This is a difficult and highly critical skill for which frequent practice can be helpful. The normal panel or helmet-mounted displays can be used. Realistic images would be required, thus making low cost unlikely. Over all, sensor-based target acquisition training (combined with sensor-based weapon system operation training) is a reasonable candidate for on-board CIG.

Weapon Delivery - Training for employment of three types of weapons will be discussed: bombs, guided missiles, and guns. These have in common the fact that they are suitable candidates for on-board CIG training, that they can be trained in a cost-effective manner with this approach, and that they only require CIG capability to be at a relatively simple three-dimensional graphic level. Sizeable portions of each of these tasks can be trained with panel-mounted and Head Up Displays commonly found in operational aircraft, although, for roll-ins, a helmet-mounted display would be desirable. It should be noted that the full field of view of the terrain and sky would be provided by the real world, while only the target need be inserted on a display. Thus, the real outside scene would provide the high detail wide field view missing in all but the most expensive ground based simulations. This full field scene would provide orientation cues as well as secondary cues to the target location should sight of the target become lost.

For bomb delivery, both the skill criticality and the frequency of practice required to attain and maintain proficiency are high. For guided missiles, the skill criticality is high. Also although the frequency of practice required is only moderate, at present very little practice is allowed due to the high cost of these weapons. Thus, the increased practice that on-board CIG would provide is needed.

Air-to-surface gunnery is a task of moderate criticality requiring frequent practice. For this task, the cost-effectiveness of on-board computer-generated imagery would be high, since the image-generation requirements are low and a suitable display (HUD) is

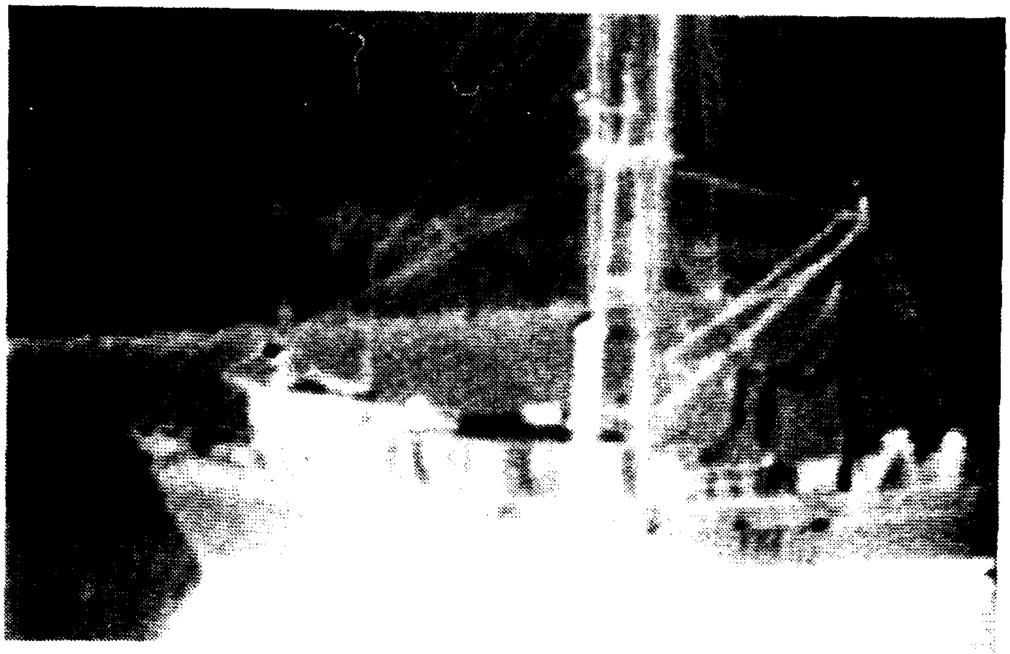


Figure 17. Forward Looking InfraRed (FLIR) Sensor Image of a Boat at Close Range.

Figure 18. FLIR Image of a Boat at Moderate Range Showing Difficulty of Target Recognition Training Task for Thermal Imaging Systems.

available in those aircraft with such a mission. Thus, the over-all applicability of on-board CIG to this task is high. The only drawback would be potential interfacing difficulties, which were not examined. Douglas Aircraft Company has been developing such a system. Since this task is a prime candidate for on-board CIG, it is recommended that this work should be carried to the flight test stage and closely monitored.

Take-Off and Landing (Carrier) - Training of carrier take-off and landing is a moderate to poor task for application of in-flight on-board CIG. However, shipboard simulation for this task is appropriate. There are several reasons for this. Only landing will be considered, since it is hard to imagine how a catapult launch would be simulated in mid-air. In favor of carrier-landing training are the following facts: the field of view of the usual head up display is adequate for such training (since only minimal crab angles are used, given that the ship always steers to avoid the need for crab); the CIG requirements are minimal (only a night representation of the carrier lighting, including Fresnel Lens Optical System (FLOS), is required); and the task is a difficult and dangerous one, requiring continual practice.

On the other hand, there are several factors weighing against in-flight carrier-landing training. A certain element of danger would remain. This stems from the fact that simulated landings with the real aircraft would, of necessity, take place at altitudes where the aircraft can fly at normal landing speeds and will have normal handling qualities. This limits the maneuver to less than about 5,000 feet altitude, a small and not comforting excess above stall recovery requirements. Another consideration is that the approach would have to broken off at a simulated altitude above the deck of about 100 feet. If not, some form of counter-productive training would occur, since either the wrong air speed would have to be established, or the plane could likely stall. The speed of an aircraft is determined by the angle of attack. Thus, during a normal carrier landing, the aircraft angle of attack is chosen to give the minimum safe air speed. Simultaneously, however, the engines are generating maximum non-afterburner power. When landing on a deck, this allows for a go around if the arresting gear is missed, since the deck will reduce the angle of attack to zero, forcing the aircraft (already at high thrust) to gain air speed rapidly. When approaching a "phantom deck," no such safety margin exists, though the aircraft would still be flying at dangerously slow speeds.

Another consideration is that the practicing aircraft would be flying in a "dirty" configuration, using much fuel. Following this, it would still either have to execute an actual successful carrier landing, or retain enough fuel to reach a land base. In the latter case it could be wiser to have practiced landings at that base in the first place.

Since a pilot who is trained successfully in landing at night will probably be successful also during the day, and since day imagery is more complex to generate and display, daytime carrier-landing training is considered to be less cost-effective than night training. Another significant benefit of night versus day training is that it concentrates the pilot's attention on the essential cues, since there are fewer distractions.

In summary, although in flight simulated carrier landing might be nice to have, it does have its drawbacks and is not one of the more appropriate tasks for in-flight on-board CIG development.

A better approach to carrier landing training while deployed would be to use one of the ship-board simulation techniques described above in the section entitled "Specific Results of CIG Survey (Ground Based Simulation)."

Take-Off and Landing Training (Fixed Base) - For a Navy pilot, there is essentially no difference between fixed-based landing training and carrier-landing training, except that training on a fixed base is safer. This presumes, as is the usual case, that the fixed base is set up to simulate a carrier deck. Thus, the previous comments about carrier-landing training apply to fixed-base landing.

Low Level Flight - Low level flight training is a moderately to highly applicable task for on-board CIG. It is best applied to aircraft designed for low-level missions at night and in bad weather conditions. In such aircraft, the pilot relies completely upon in-cockpit displays. Thus, by definition, adequate displays are available. It is a skill of high criticality, requiring frequent practice to attain and maintain. Cost would be moderate to high depending upon the type of display being simulated. Some low-level flight displays contain only symbology and graphics, thus being relatively easy to simulate or stimulate. Other displays, depicting a sensor view of the outside world, would be more costly to simulate; however, this may also be cost-effective for reasons of safety.

Low Level Navigation - The same considerations pertain as for low-level flight. An additional consideration is that low-level flight could be practiced over generic terrain as long as the simulated terrain is always safely above the actual terrain being overflown. On the other hand, low-level navigation would necessarily be performed over a representation of some specific (albeit possibly ficticious) terrain. Realistic imagery could provide a useful mission rehearsal capability.

Rotary Wing

Visual Navigation - Visual navigation at moderate to high altitudes (low level is considered separately) is considered moderately suitable for on-board CIG for those aircraft equipped with helmet-mounted displays (at present, only the planned CH/MH-53E). For other aircraft, on-board CIG is unsuited for this task, since it is by definition an out-of-the-cockpit, visually oriented task for which there are no suitable displays short of helmet-mounted ones. The task is considered of moderate criticality and requires moderate practice. Only realistic imagery would suffice, adding to its lack of appeal as an on-board CIG application. As with fixed wing aircraft, sensor based navigation does not have these drawbacks and is a potential on-board CIG candidate.

Visual Reconnaissance - The comments on visual navigation apply here as well, with the exception that visual reconnaissance is a somewhat more critical task requiring more practice to attain proficiency.

Target Acquisition - This task is a good long term candidate for on-board CIG. It is a critical skill and is difficult to develop, requiring a great deal of practice. Once mastered, it is relatively easy to maintain with the exception that new targets must always be learned. In rotary wing aircraft, target acquisition is usually performed with the aid of an optical magnifying system including a television display. Inserting or embedding of artificial targets into a real scene may become feasible, thus affording much practice. Realism is required in system operational characteristics such as noise, resolution, gain, and level controls, as well as in the target signatures themselves. (See Figure 19.)

Weapons Delivery - This task would apply mostly to the upcoming AH-1T helicopter. This machine will have a head-up display and a helmet-mounted gunner sight without a

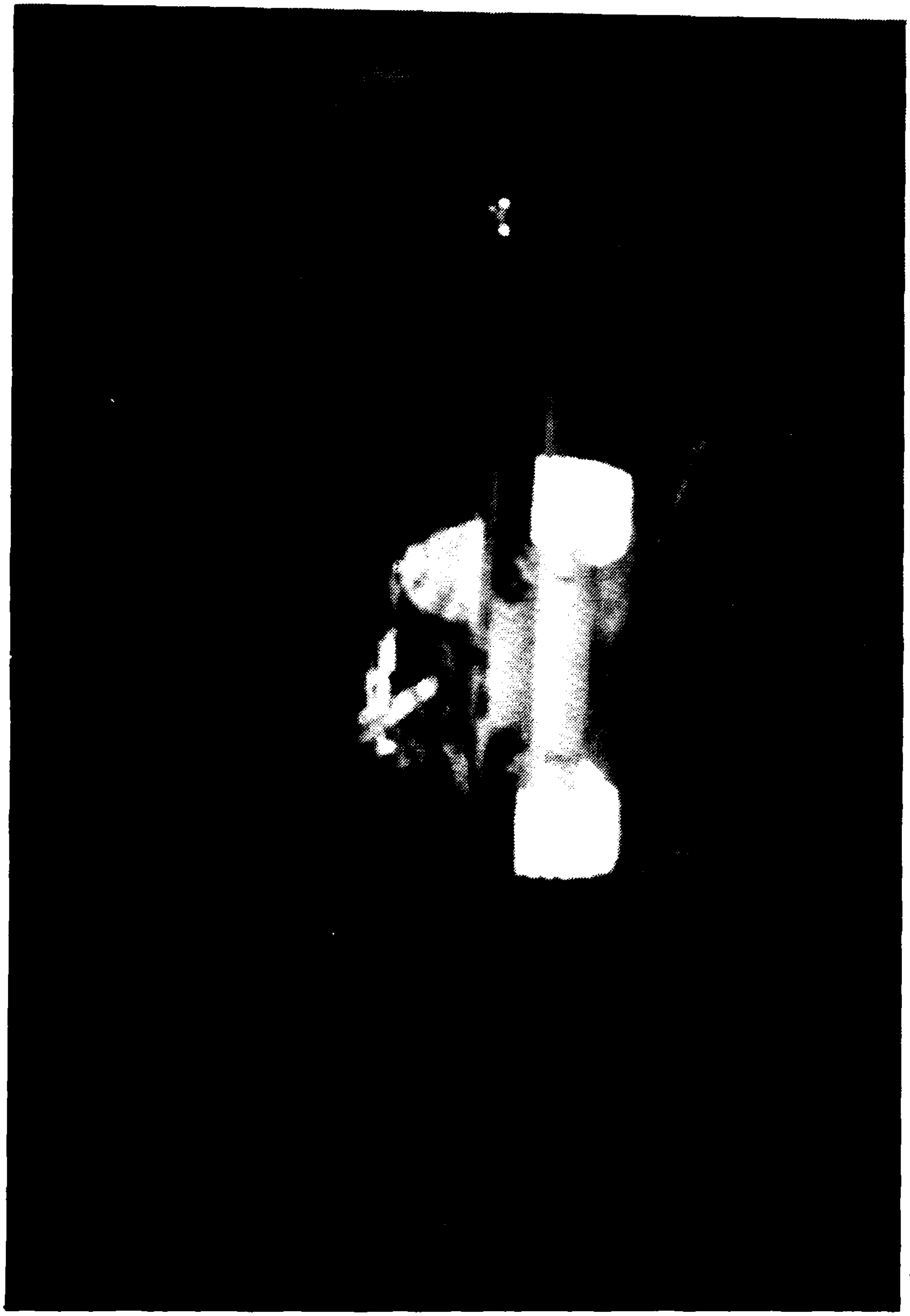


Figure 19. FLIR image of a tank in which the tank image has been reduced and re-inserted into the background at right center. (courtesy of the Army Night Vision and Electro-Optics Labs, DCS Corporation, and the Defense Advanced Research Projects Agency).

display. It will fire a broad range of weapons which require little sophistication in the displays. On-board CIG is not seen as particularly applicable, because extensive use of ground-based simulation is likely, because many of the tasks are too simple to warrant it, and because the displays are inadequate for application of on-board CIG to the other tasks.

Anti-Submarine Warfare - Anti-Submarine Warfare does not include any task that can be trained with on-board CIG alone or for which graphic images even play a major role. The sonar operator's skill is mainly in interpretation of acoustic signals transmitted to his head phones. These are used in conjunction with a simple CRT display showing range rings and the locations in azimuth and range of a sonar signal return source.

Confined Area Maneuvering - On-board CIG does not lend itself to training of confined area maneuvering. Helmet Mounted Displays giving a large field of regard would absolutely be required. Even stereo displays would be highly desirable for judging clearances. Thus, the display requirements severely restrict the applicable aircraft. In addition, since the operation requires hovering, it must be trained at low altitude, as many helicopters need the ground effect to hover. It would require fairly realistic imagery of a level at the high end of the graphic three-dimensional category.

Low-Level Piloting - Rotary wing low-level piloting is a moderately to highly desirable task for on-board CIG for those aircraft to be equipped with helmet-mounted displays, such as the CH/MH-53E. It is a highly critical task requiring frequent practice. Cost-effectiveness of on-board CIG should be moderate, given that the CIG requirements are for either realistic imagery or high-density, three-dimensional graphic imagery, while the task is indeed a critical one.

Low-Level Navigation - Low-level navigation is even more desirable than low-level flight per se. In this case, realistic imagery is required. Low-level navigation is a very difficult and critical task, requiring frequent practice. It is a task that would benefit immensely from a rehearsal capability. Again, it applies only to those rotary wing aircraft with helmet-mounted displays. Cost-effectiveness of CIG would be high, since there is no other way to perform mission rehearsal.

Take-off and Landing (Ship) (Day/Night) - Take-off training is not a problem, so only landing will be discussed. Given that helicopters frequently do not take the same long approach paths as fixed wing aircraft and can approach at large yaw angles, a helmet-mounted display would be required to obtain sufficient field of regard. The level of CIG capability would be in the three-dimensional graphic category or better. As with fixed wing aircraft, actual touch-down could not be simulated in flight due to aircraft handling qualities, performance limitations, and safety requirements. Although this skill is one of high criticality requiring frequent practice, it is not a good candidate for on-board CIG. Adequate displays are normally unavailable, and practice of the final stages (the most critical) would be counterproductive in the air, since ground effect is important and necessary for safety.

Take-Off and Landing (Fixed Base) (Day/Night) - If one can take off and land from a ship, taking off and landing from a fixed base should pose no problem. Likewise, day landings should present no mystery given that night landings have been mastered.

Mine Sweeping - In mine-sweeping, not only is low-level flight maintained for hours at a time, but a device must be towed in a precise pattern. This is a difficult and critical task requiring much practice. As a result of the tow, the aircraft is in a severe pitched condition throughout the operation. Since this operation is performed at sea, where altitude is difficult to judge in the real world, realistic imagery would be mandatory. A helmet-mounted display would be required. This would be a very suitable task for application of on-board CIG based training if it could be practiced without the tow and at a safe altitude. Unfortunately, this was found not to be the case. Based upon discussions with two rotary wing test pilots, it was concluded that towing flight could not be simulated in the aircraft without actually having a towed object. With the towed object, the maximum altitude achievable is about 400 feet. This does not offer much more safety than the normal altitude of 200 feet. In addition, the task of towing an object in a particular pattern gets more difficult as the length of the tow line is increased. Thus mine sweeping was not assessed as a good application for on-board CIG. It should be noted, however, that simple recording and display for feedback of the actual paths taken by the tow and by the helicopter would be valuable both for operation and for training.

SENSOR ENVIRONMENT

General Discussion - Although this category does not represent a set of training tasks per se, it is discussed as a group in this section because of the characteristics sensor systems have in common. For example, display availability is not a problem for any sensor image simulation/stimulation, since cockpit displays for these images already exist. The only potential problems in this regard are the availability of data/video paths from the image generator to the displays, and display drawing technique limitations that may be imposed by a particular display.

An example of this would be a FLIR system that normally generates a vertical raster display. Such a system might require a similar drawing mode from the image generator, as opposed to more typical horizontal raster or calligraphic modes. Detailed examination of each specific aircraft will be required to establish such restrictions. For instance, FLIR imagery in the A-6E aircraft is displayed in a non-standard vertical raster format; however, the display upon which this is presented also is capable of displaying standard 525-line, horizontal raster images for other weapon systems. In this case, the decision regarding appropriateness of the use of a 525-line horizontal raster simulation for the FLIR should be based upon modeling and comparing performance with each drawing mode.

Radar/Landmass - On-board simulation of radar land mass images was concluded to be moderately appropriate. The most useful mode for this type of simulation would be for specific rehearsal. That is, the exact area to be overflown on an upcoming mission would be simulated for practice of that specific mission.

It is necessary to examine two points with regard to radar landmass training possibilities. First, radar landmass images are particularly difficult to simulate. It can be inferred that other approaches, such as the use of recorded imagery, would be more successful than CIG in this task. Secondly, radar images require interpretation on the part of the operator. Therefore, realistic imagery is key to performance. Given these considerations, it could be concluded that CIG is not the ideal mode of training radar landmass skills. Recorded real images could be used to practice general radar interpretation skills. An exception does exist for mission rehearsal and full mission training. For this situation, real images may be unavailable, in which case realistic rehearsal requires

generation of artificial images of the actual areas to be overflown in an upcoming mission.

Forward Looking Infrared (FLIR) - This is a good training application for on-board CIG. Although this type of sensor system has much in common with the Radar land-mass, it differs in one important characteristic: unlike radar images, FLIR images of the same scene vary with time of day and weather. Thus, while real radar images may be adequate and available, real FLIR images are not. Although many real FLIR images are available, they do not span the range of conditions, targets, and backgrounds necessary for systematic training of FLIR image interpretation and target recognition. Thus, computer-image generation of these images is warranted. Such generation could be either in real-time or non-real-time for playback in real-time. It is potentially possible to insert computer-generated targets into the actual FLIR image. (Fig. 19). Alternatively, the whole image could be simulated.

TV Guided and TV Data Link Weapons - Training of TV Data Link guided weapons is of high interest as an on-board CIG application. The images are in the visual spectrum and hence are less unusual for the operator than are other sensor images. There are, however, guidance control techniques to be practiced. This becomes a consideration for example in the GBU-15 glide bomb and extended range Walleye. For such applications, a fairly simple three-dimensional graphic target image would suffice, since target recognition is not the prime instructional goal. On the other hand, for other types of TV-guided weapons, realistic image characteristics are required. The weapons in this category are ones which do not require operator guidance after launch, such as the Maverick missile. Specifically, the requirement for realism stems from the need to correctly portray the lock-on and break-lock characteristics of the system. The frequency of practice required to master and maintain these skills is moderate, but present opportunities to obtain this practice are in some cases almost non-existent. Given the availability of displays, allowable simplicity of the images, and the need for training, this task should be addressed cost-effectively by on-board CIG.

Sonar - This topic was discussed in the section on Anti-Submarine Warfare.

Electronic Countermeasures - This is a good candidate, since it is a critical task not frequently practiced and entails no inordinate display or CIG problems beyond interfacing.

Overall Analysis

The survey results must be analyzed with regard to the factors found to be most salient in determining suitable applications. Applications can then be grouped according to their suitability for on-board CIG training.

THE DRIVING FACTORS

Cockpit display compatibility and interfacing problems were determined to be the most significant factors for selection of suitable on-board CIG applications.

Displays

The lack of a wide field of view, out of the cockpit display (with a few exceptions) limits many potential applications. Examples of these are the following:

- air refueling, formation flight,
- air combat maneuvering
- rotary wing threat avoidance,
- fixed wing visual navigation,
- fixed wing reconnaissance,
- rotary wing gunnery,
- rotary wing shipboard landing,
- confined area maneuvering, and
- rotary wing low level piloting and navigation.

A few aircraft have or will in the future have helmet mounted displays. The CH/MH53E and LHX are examples of these. For fixed wing aircraft, helmet mounted displays may become available in the future, but they will likely have a narrow field of view (10-12 degrees). This will be quite sufficient for air combat maneuvering against real targets and for exploration of the flight envelope without a target. But, based upon the results of simulation tests at McDonnell Douglas, it will not be adequate for air combat maneuvering practice against artificially generated targets.

Helmet mounted displays for fixed wing aircraft are limited to small instantaneous fields of view by pilot safety considerations. The helmet center of gravity, angular momentum, weight, and size (in that order) must fall within tight constraints for safe operation at high g loads and during ejection. These considerations have prevented, thus far, the appearance of a wide instantaneous field of view helmet mounted display. A display designed for training use only would still have to meet all of these criteria.

For rotary wing aircraft, the situation is different. The CH/MH53E and possibly the LHX will have 40 degree field of view helmet mounted displays. On-board CIG for the above-mentioned tasks would apply only to these aircraft.

Given this general lack of out of the cockpit view displays, it is reasonable to apply on-board CIG to the available displays. This places emphasis on aircraft with all weather/night missions, since these have displays and sensors specifically designed to avoid the need to look outside the cockpit. For example, terrain following and avoidance displays are normally generated artificially and could readily be duplicated with on-board CIG. Sensor displays require more sophisticated computer image generation, but not beyond the expected capabilities of the state-of-the-art in the 1986 and beyond time frame that is the earliest such a program will begin.

Interfacing

The other driving factor in selection of on-board CIG applications will be the ease or difficulty of interfacing with particular aircraft. Although not specifically included within the scope of this study, an initial examination of aircraft interfacing problems was conducted when, during the display survey, this was found to be a significant consideration. In the newer aircraft (F-18, A-6F, F-14D, CH/MH53E, LHX) interfacing will become easier since the trend is toward the use of a common data bus (MIL-1553) as well as a video bus architecture. In many of these aircraft, multi-function displays are used. Multifunction displays generally comprise a cathode ray tube (CRT) surrounded by pushbuttons which are labeled on the adjacent portions of the CRT face and can change function under software control. Such displays may combine raster scan and calligraphic (line drawing) display modes. Aircraft using these displays should be less difficult for on-board CIG interfacing than older aircraft which use special purpose CRT displays and which do not have a bus based avionics architecture.

Computer Image Generation Technology

The development of on-board computer image generation equipment suitable for training applications does not appear to be limited by the state of the art. Such a development can derive benefit from the following factors:

- The level of CIG required covers a broad range, from simple symbology already being produced in flight worthy hardware to complex realistic sensor simulations that would indeed tax the state of the art. Clearly, a CIG system can be developed which serves at least a major portion, if not all, of this range.
- On-board CIG systems are already under development (largely by the US Air Force) for operational applications.
- The VHSIC technology program could be applied in development of on-board CIG yielding improved ratios of performance to weight and size.

Training Needs

The priority for selection of tasks is based upon training needs once the feasibility of the application is assured by examining display, interfacing, and CIG requirements. The training needs in this analysis have been summarized by the criticality of the skill and the frequency of practice required to acquire and maintain the skill. Another factor considered is whether the skill is presently being trained with satisfactory frequency, quality, and cost.

Since training of deployed forces is a major goal of the on-board CIG program, emphasis has been placed upon tasks which have one of the following characteristics:

- Frequent practice is required to maintain the skill.
- The skill is a combat related skill not fully addressed in initial training.
- The skill continues to improve with prolonged training.

Examples of tasks having these characteristics are, in order, carrier landing, threat avoidance, and air combat maneuvering.

MOST SUITABLE APPLICATIONS

Based upon the results discussed above, the tasks most suitable for on-board application of CIG were determined to be as follows:

Air to air, fixed wing threat avoidance
Air to air fixed wing air intercept
Air to ground fixed wing target acquisition
Air to ground fixed wing weapons delivery (bombs, guided missiles, guns)
Fixed wing low level flight (sensor based)
Fixed Wing low level navigation (sensor based)
Rotary wing low level piloting
Rotary wing low level navigation
Sensor environment, infrared
Sensor environment, TV data link
Sensor environment, electronic countermeasures

These tasks have in common that they are significantly critical and require practice beyond that presently available to achieve optimum proficiency. Incorporation of the required display and CIG capabilities is feasible, and the additional training opportunity provided is relevant to pilots who have completed initial training and are deployed.

LEAST SUITABLE APPLICATIONS

The least suitable applications for on-board CIG are as follows:

Task	Main Reason not Suitable for On-Board CIG
Air to air fixed wing air refueling	(No Available Display)
Air to air formation flight	(No Display)
Air to air rotary wing formation flight	(Frequent Real Practice)
Air to air rotary wing threat avoidance	(No Display)
Air to surface fixed wing visual navigation	(No Display)
Air to surface fixed wing visual reconnaissance	(No Display)
Air to surface fixed wing take off and landing (fixed base-day)	(Night Adequate & Cheaper)
Air to surface rotary wing weapon delivery-gunnery	(No Display)
Air to surface rotary wing anit-submarine warfare	(Visual Display Task Component Not Major)
Air to surface rotary wing confined area maneuvering	(No Display)
Air to surface rotary wing take off and landing (fixed base-day or night)	(No Display)
Air to surface rotary wing take off and landing (ship-night or day)	(No Display)
Air to surface rotary wing mine sweeping	(Can't simulate tow & can't fake low altitude)
Air to surface rotary wing sonar	(Displayed information is less important than sound)

In most cases, an application is unsuitable because of the lack of an adequate display. Mine sweeping requires towing an object in a precise pattern at low level for long periods. This would be a good candidate if it were possible to simulate the handling qualities of the aircraft in this task without the tow. Unfortunately, this is not possible in the actual

aircraft. When towing, the maximum altitude achievable is about 400 feet. Thus, no advantage in safety is to be had through on-board CIG. In the case of formation flight, not only are there no adequate displays, but there are frequent opportunities to practice this without the aid of simulation. Finally, for fixed base day take off and landing, the fact that training can be accomplished with a simpler night image makes the display of day images unwarranted. In addition, for aircraft without helmet mounted displays, the field of view of a head up display would be inadequate for some crab angles. This problem pertains only to fixed base landing, since aircraft carriers steer to minimize the need for crab angle.

ESTIMATED DEVELOPMENT AND IMPLEMENTATION COSTS

A wide range of development and implementation cost is possible depending on the objective. The cost could be low for simple investigation of training needs and available techniques for avionics already under development. This effort need not impact eventual hardware costs, although a requirement for additional software effort may result. At the other end of the spectrum, development and flight test of a CIG pod could run as high as $50 million if the pod is presumed to be of a size and complexity comparable to a Maverick missile (462 lb.). This is probably the worst case figure since it is unlikely the CIG system would need to be that large. The cost of avionics scales roughly as the weight. Some example rough cost breakdowns are given in Table 14. These were derived using historical data from NAVAIR on the cost per pound of avionics equipment and the ratios of various ancillary task costs to the hardware cost. The assumed minimum weight corresponds to an existing flyable digital map generation system and would lead to a program cost of $3,200,000. Table 13 gives characteristics of several relevant systems as compared to a Maverick missile. As can be seen from this, quite a bit of computational horsepower can be squeezed into a package less than the size and weight of a missile.

One of the key factors affecting overall program cost will be the number of types of CIG systems to be developed. The goal should be for one CIG system to serve a wide range of training tasks on a wide range of aircraft. Clearly, each training task and aircraft will require some unique software for that specific application. Thus, the system design should allow for these software changes to be made readily. In addition, the interface to each aircraft will likely be different. Two approaches to solving this problem are possible. The CIG pod could internally generate some of the standard information it

TABLE 14

Cost Estimate for On-Board CIG

Cost Build Up Complexity=Avionics	Minimum	Likely	Range	Maximum
Weight**	25 lbs	100 lbs	200 lbs	462 lbs
Inflation index used ('89 - '83)=14,311				
R&D Units at 10,500 lbs	262,500	1,050,000	2,100,000	4,851,000
Number of R&D Units x 6	1,575,000	6,300,000	12,600,000	29,106,000
Software (2/3 of 1st Unit Hardware Cost)	175,000	700,000	1,400,000	3,234,000
Integration (30% of 1st Unit +10% of subsequent)	210,000	840,000	1,680,000	3,880,800
System Eng./Management (15% of total hardware, software and Integration)	294,000	1,176,000	2,352,000	5,433,120
ILS (15% of Proto-Hardware Cost)	236,250	945,000	1,890,000	4,365,900
Training (1% of Proto-Hardware Cost)	15,750	63,000	126,000	291,060
Data (1% of Proto-Hardware Cost)	15,750	63,000	126,000	291,060
Special Support Equipment (8% of Total Hardware Cost)	126,000	504,000	1,008,000	2,328,480
T&E (15% of Hardware Cost)	236,250	945,000	1,890,000	4,365,900
Spares (20% of Hardware Cost)	315,000	1,260,000	2,520,000	5,821,200
Subtotals	3,199,000	12,796,000	25,592,000	59,117,520

*Weight Range: 25 lbs (Harris DMG) - 462 lbs (Maverick equivalent weight available)

would need, thus avoiding some interfacing variations. Secondly, the interface could be developed as a separate aircraft unique module that not only could provide signal paths, but could download aircraft unique software to the main CIG module.

The rough numbers of on-board CIG systems that would be needed upon successful system development and demonstration can be estimated. Navy plans call for 15 carrier groups. The composition of the carrier air wings is presently under study. The high pay off for on-board CIG would be for A-6, F/A-18, and F-14 aircraft with additional systems possible for A-7s and helicopters if affordable. Tentatively, the air wing composition may be presumed to be two F-14 squadrons, one A-6 squadron, and two F/A-18 squadrons per carrier. Although trade offs between F/A-18 and A-6 numbers are possible, the total number of squadrons is likely to be five per carrier. The number of on-board CIG systems required is related to the number of aircraft which would employ them at any one time. Allowing for spares, four to five per squadron is estimated. In addition, there are two Reserve Air Groups (RAGs), one on each coast. An additional 20 systems may be presumed for these. Thus, the total estimated fighter/attack requirement is:

$$\frac{5 \text{ OBCIG's}}{\text{squadron}} \times \frac{5 \text{ squadrons}}{\text{carrier}} \times 15 \text{ carriers} + 20 \text{ for RAGS} = 395 \text{ OBCIG systems}$$

In addition, 36 for helicopter applications would bring the total to 431.

CONCLUSIONS AND RECOMMENDATIONS

A wide variety of training problems can be addressed with on-board CIG.

However, given the present state-of-the-art in on-board displays, and the fact that few aircraft have helmet mounted or other ultra-wide field displays, and considering safety issues, on-board CIG can not replace wide field-of-view ground based visual simulation. Possible exceptions to the field-of-view limitation are (1) the CH/MH-53E/HNVS system, which will incorporate an Integrated Helmet and Display Sight System (IHADSS), and (2) the JVX and F-14D aircraft currently under development for which helmet-mounted displays are being considered. An additional consideration is the expense of airborne training (including reduced life of the equipment). This must be contrasted with the high task repetition rate and freedom from weather dependence available with

ground based systems. Therefore, on-board CIG should be viewed as a supplement to ground-based training rather than a replacement.

There are a broad range of significant training advantages that could accrue from increased utilization of on-board training. On-board training is best applied to those tasks and conditions which are not now adequately addressed by ground based simulation. These include:

o Tasks in which realistic g loading, workload, and or "pucker factor" are significant.

  - Air-to-ground weapons delivery (particularly.

    Artificial targets generated on-board
    Scoring feedback
    Adaptive training with cue supplements

  - Air-to-air combat

    Artifical targets for air intercept
    Energy-maneuverability diagrams
    Energy management in thrust vectored aircraft

  (NOTE: Lack of helmet coupled displays will limit these applications.)

o Tasks which must be practiced away from ground based simulation facilities and flight ranges such as when deployed on a carrier.

  - On-ship, on-board simulation
  - In-flight, on-board simulation

o Tasks requiring frequent practice to maintain proficiency.

o Tasks which could benefit from more combat realistic practice

- High threat environments
- Simulated firing of high value weapons

  Walleye
  Maverick
  GBU-15
  Laser Guide Bombs
  Harpoon

The selection of tasks for on-board training is, for the most part, influenced by available displays. Next in order is the compatibility of the training problem with CIG techniques as influenced by user community needs and existing methods. The availability of sufficient CIG capability will not be a significant issue except for some tasks that are particularly demanding in terms of scene content. This does not mean that all appropriate on-board CIG systems already exist. Rather the technological development of an appropriate system (under NTEC guidance) is achievable. For instance, such a system could be designed and built without resorting to VHSIC technology, although availability of that technology would certainly be helpful in enhancing system capabilities. The use of VLSI with high density packaging techniques such as leadless chip carriers and hybrid circuits could accomplish a useful on-board system. Upcoming technologies such as VHSIC and Wafer Scale Integration (WSI) would be helpful as they become available.

Specific techniques available for interfacing on-board CIG with each potentially applicable aircraft should be examined. This surfaced during the study as a serious potential limitation of applications for on-board CIG. Based upon an examination of the results, specific aircraft and applications should be targeted for initial on-board CIG development. Now is a good time for potential on-board CIG training to be considered in the development cycle of aircraft such as the A-6E Upgrade, CH/MH53E, and F-14D.

A number of approaches could meet on-board training needs. One of these, development of an internally mounted training system is an important, but secondary and longer term goal which can be pursued by representing training interests in the aircraft development cycle in cooperation with the primary aircraft development agencies. The primary and shorter term goals can avoid the problem of aircraft internal space availability in two ways, which may be pursued in parallel. One is to develop training

applications (viz. software and techniques) utilizing already existing or planned avionics. A good example of this potential is the joint USAF/Navy advanced radar threat warning project (INEWS). This system does not yet address potential embedded training utilization of the system (which could modify or amplify the design specifications). At this stage, it may not be too late to study potential training methods, software, and hardware approaches leading to contract modifications to add such capabilities.

The second way to avoid the space availability problem to develop hardware that can be temporarily installed for training missions only. Such hardware could be mounted to a weapon station (for aircraft equipped to handle the appropriate weapons). It need not conform to the weapon shape, but should have the same drag and weight effects. A precedent for this approach is the mounting of the Tactical Air Combat Training System/Air Combat Maneuvering Range (TACTS/ACMR) transmitter/data collection devices. Appropriate data path availability will have to be established.

As a starting point, a system could be developed using relatively simple CIG to work out aircraft interfacing and specific training techniques. The Naval Air Development Center (NADC) is embarking on a CIG pod development program to study advanced control and display techniques. The CIG pod is expected to generate relatively simple graphic images, since its purpose is to test new flight control and display concepts. There are no requirements in this development for realistic training images. To fill this vacuum, development of a training oriented CIG pod focusing on of requirements for high quality realistic images would be a logical complement.

The Naval Air Test Center (NATC) at Patuxent River, Maryland is investigating aircraft interfaces and operates an aircraft simulation facility specifically designed to emulate the various avionics systems on a number of aircraft. Since the on-board CIG concept overlaps previously clear borders between training and operational equipment, it is expected that close cooperation between the Navy Training Community and avionics laboratories such as NATC, NADC, and the Naval Weapons Center (NWC) would benefit the overall program substantially.

Finally, a simulation display could be used either on the carrier deck or in actual flight. In the on-deck approach, large field-of-view displays (for example helmet

mounted) could be used allowing enough field-of-view for portrayal of out of the window scenes. This would be the best way to address the carrier landing task.

By addressing critical training needs for deployed forces, an on-board computer image generation program can be a significantly benficial complement to existing training methods.

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APPENDIX A
VIDEO TAPE SCRIPT

NTEC SCRIPT

1. Naval Aviation -- a modern, multi-mission aerial arsenal capable of global operations in defense of America's interests on land, at sea, or in the air.

2. Today's technologically sophisticated naval aircraft and weapons systems place unprecedented demands on the skill and combat readiness of Navy pilots.

3. Equally demanding is the combat environment in which naval aviators will be called upon to perform their missions.

4. Maintaining pilot proficiency at a consistently high level is not only demanding, difficult, and dangerous. It's a never-ending task.

5. Air-to-surface training operations require a sizeable range, something that's not available in many parts of the world. Even when a range is available, its distance from bases or carriers may severely curtail time on target.

6. Air-to-air training operations can approach the reality of combat through the precise coordination of numbers of aircraft and close cooperation among many organizations. But, because of the high cost and the logistics involved, pilots rarely get a chance to participate in such large scale exercises.

7. The necessarily high pricetag on each hour of flying training has already reduced available in-flight training time to a minimum, making it all the more important to squeeze the utmost in utility from each flight hour.

8. While all flight time increases pilot proficiency, factors of cost and complexity drastically reduce the proportion of flying hours allocated to realistic, high-threat-level combat training. Combat scenarios are restricted by equipment availability and flight rules. In most cases, pilots can neither carry nor expend high-value weapons, and their opportunities to actually deploy such weapons are few and far between.

AD-A145 214 ANALYSIS OF ON-BOARD CIG (COMPUTER IMAGE GENERATOR) APPLICATIONS FOR AIRCREW TRAINING(U) DCS CORP ALEXANDRIA VA D B COBLITZ APR 84 DCS-LT0010 NAVTRAEQUIPC-IH-353 N60921-82-D-A075 2/2

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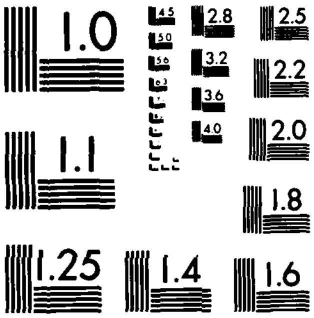

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

9. Statistics from World War II, Korea, and Vietnam show high loss rates associated with a pilot's first few combat missions, and greatly improved survivability thereafter.

10. Should hostilities occur, Navy pilots will have to react instinctively to real-world conditions of high stress, powerful distractions, and surprise.

11. Ground-based simulators, when available, are invaluable for initial pilot training, transitions, and procedures training. Today's ground-based combat mission simulators, with wide field of view visuals, and computer-generated combat environments, move the pilot a step closer to combat practice. But ground-based simulators can only approximate the reality of actual flight; and, for pilots deployed for long periods on carriers at sea, opportunities for realistic training in high-threat combat situations are severely restricted.

12. More realistic practice can be brought into the cockpit through the use of on-board computer-generated images. This technology, already successful in ground-based training, has advanced to the point where computer image generating systems can be carried aboard operational aircraft, resulting in significant advantages for combat proficiency training.

13. Let's take a look at how an OBCIG system will work in some typical aircraft missions.

14. No narration (Air-to-Surface)

15. For the air-to-surface mission, an OBCIG can provide synthetic targets.

16. Simulated operation and delivery of a variety of weapons can enrich many hours of otherwise routine flying.

17. And, while still in flight, an aircrew can receive scoring feedback immediately after each simulated weapons firing.

18. Simulated threat envelops can be presented.

19. And, active threat avoidance training can be accomplished by artificially driving cockpit warning displays.

20. No narration (Air-to-air).

21. For the air-to-air mission, weapons envelop recognition can help pilots avoid firing when short of minimum range.

22. The real target shown in this scenario will be replaced by a synthetic target on the head-up display (HUD).

23. Energy-maneuverability diagrams will also be available. This type of diagram shows a pilot how his present turn rate versus airspeed compares to the performance limits of the aircraft. This allows the pilot to become quickly familiar with flight at the boundaries of his aircraft's capabilities.

24. Threat avoidance training will be anhanced by the display of threat envelops.

25. No narration (Low-level Flight, Terrain Avoidance, Night, Bad Weather).

26. An OBCIG can provide capabilities similar to the Airborne Terrain Electronic Mapping System (ATEMS) shown here, which is presently under development for operational purposes.

27. Low-level flight can also be simulated with the HUD and panel displays in all-weather aircraft.

28. A Helmet-mounted Display, coupled with a Night Vision System, can generate a synthetic scenario demonstrating *low-level flight* and *terrain avoidance* while operating at altitude. In fact, a helmet-mounted display can be developed to serve as a training display device in a variety of aircraft.

29. No narration (Sensor-based weapons delivery)

30. OBCIG capabilities will include radar and infrared sensor simulation.

31. This will significantly increase the amount of practice aircrews will receive in employing high-value, sensor-based weapons.

32. No narration (what needs to be done?)

33. With space and weight aboard aircraft at a premium, there is little tolerance for equipment installed for training purposes only. Two parallel approaches will be employed to avoid this potential objection.

34. One approach will concentrate on developing training modes for operational on-board computer image generating equipment already under development. The experienced training designers of the Naval Training Equipment Center (NTEC), working alongside the engineers of the Naval Air Development Center and other avionics developers, can design useful integral training modes into operational systems. Facilities such as the Visual Technology Research Simulator can be used to study and evaluate potential on-board training techniques.

35. The second, less limited, approach is to develop an on-board computer image generating pod that can be mounted on an existing weapon station for training missions. The pod will add no additional weight or bulk to the aircraft's combat profile, since it will be mounted only during training missions.

36. The computing power in these commercial image generating equipment racks will be reduced to the size of ordinance typically carried on an aircraft weapon station. This will be accomplished by combining standard military packaging techniques with the latest in Very Large Scale Integrated Circuit Technology.

37. Appropriate interfacing between the pod and available cockpit displays will be developed.

38. And specific techniques will be designed to fully exploit the advantages of this new training tool.

39. At NTEC, the capability already exists to develop a practical, non-intrusive, cost-effective extension of simulation activities into the cockpit of operational aircraft. The payoff from on board computer image generation will be the ability, at last, to train combat tasks while flying the real aircraft; even when deployed far from normal training facilities. Through repeated exposure to graduated, increasingly intense threat levels, naval aviators can gain the confidence and experience, the all-important razor's edge of proficiency that, in combat, makes all the difference.

40. Music and credits.

APPENDIX B
LIST OF CONTRIBUTING ORGANIZATIONS

McDonnell Douglas Electronics Co.
St. Charles, MO 63301

General Electric Co.
Binghampton, NY 13902

Rediffusion Simulation Inc.
Arlington, TX 76011

Ikonas Graphics Systems Inc.
Raleigh, NC 27606

Adage Inc.
Rockville, MD 20850

Boeing Aerospace Co.
Seattle, WA 98124

W.W. Gaertner Research Inc.
Stamford, CN 06903

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